Conservation Practices and Water Quality Trends in Sulphur Creek Wasteway and Granger Drain Watersheds, 1997 to 2002

South Yakima Conservation District

in collaboration with the Roza-Sunnyside Board of Joint Control

December 2004

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Funded through the Centennial Clean Water Act Fund

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by

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Photograph on cover: Sunnyside Canal and diverse irrigated crops north of Sunnyside, Washington, September 2000.

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Acronyms

BMP	Best Management Practice
DDT	Dichlorodiphenyltrichloroethane
EQIP	Environmental Quality Incentives Program
GIS	Geographic Information System
NRCS	Natural Resources Conservation Service
NTU	Nephelometric Turbidity Unit
PAM	Polyacrylamide
RSBOJC	Roza-Sunnyside Board of Joint Control
SYCD	South Yakima Conservation District
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WCC	Washington State Conservation Commission
WSU	Washington State University

Preface

In November 2000, the Roza-Sunnyside Board of Joint Control (RSBOJC) received a $10 million loan from the Department of Ecology to offer low-interest loans to landowners converting from rill irrigation to sprinkler or drip irrigation systems. The Natural Resources Conservation Service (NRCS), responsible for reviewing the irrigation designs and writing the farm plans for the new sprinkler or drip irrigation systems, was concerned about their ability to review the anticipated 1200 new systems in a timely manner with existing staff already faced with record number of applicants for federal cost-share programs. To assist NRCS, the South Yakima Conservation District (SYCD) obtained a $127,287 grant from the Department of Ecology intended primarily to help NRCS review the irrigation designs and write farm plans.

One small task included in the grant was to evaluate the effectiveness of the installed sprinkler and drip systems in improving water quality in Sulphur Creek Wasteway and Granger Drain from 2000 to 2002. This report was written to conduct the required effectiveness evaluation. Because RSBOJC needed to evaluate water quality changes in Sulphur Creek Wasteway for a separate grant funded by the Department of Ecology, the report was written on behalf of both SYCD and RSBOJC. The scope of the report was expanded to include the first six years of water quality data from RSBOJC and three major sources of BMP funding to provide a broader perspective of the changes occurring in these watersheds.

Acknowledgements

The South Yakima Conservation District currently consists of four technical staff, one secretary, and five voluntary Board members. Without support and cooperation from many agencies and individuals we could not do our job – to help private landowners conserve their soil and water resources. For example, this project would not have been possible without the Roza-Sunnyside Board of Joint Control's long-term water quality monitoring network and $10 million loan program; the inventory of irrigation and crop types on over 15,000 parcels conducted by the Sunnyside Division and the Roza Irrigation District; support and encouragement from Alan Fulk, Natural Resources Conservation Service (NRCS), District Conservationist; on-the-job training in irrigation design review and farm planning provided by NRCS staff, especially Oscar Tobias, engineering technician; on-going technical support in interpreting water quality data from Stuart McKenzie, retired U.S. Geological Survey (USGS) hydrologist; and grant funding received from the Department of Ecology.

Thanks also go to Suzanne Wade, GIS specialist, Kittitas County Conservation District, who kindly developed the GIS layer for slope. Hank Johnson, hydrologist, USGS, provided essential information about basin delineations, interpreting crop inventories, and conducting seasonal Kendall trend tests. Finally, many individuals reviewed the draft report and provided valuable insights on interpreting the data, including: Stuart McKenzie; Dr. Julie Tarara, research horticulturist, USDA Agricultural Research Service; Daniel Wise, hydrologist, USGS; Bill Rice, Natural Resource Specialist, Yakima County, and Dr. Robert Stevens, extension soil scientist, with Washington State University Cooperative Extension.

Executive summary

Sulphur Creek Wasteway and Granger Drain are two of the most important irrigation return drains to the Yakima River due to their relative contribution of suspended sediment, nutrients, and bacteria. In these watersheds, soil erosion from furrow irrigation has been the single largest resource concern for decades, both in terms of the loss of a valuable resource (soil eroded from productive land) and impacts the eroded soil has on the Yakima River. Tremendous effort and millions of dollars have been spent to reduce erosion and improve water quality. This report evaluates changes in soil and water conservation practices and water quality in these two watersheds from 1997, when the Roza-Sunnyside Board of Joint Control began long-term water quality monitoring, to 2002 when data analyses for this report began.

Overall, water quality improved substantially during these years in terms of decreasing turbidity and decreasing concentrations, loads, and yields of suspended sediment, nutrients, and fecal coliform. The table below shows the 2002 value of these water quality constituents as a percent decrease from the 1997 value.

	Turbidity	**Total suspended solids**	**Total phosphorus**	**Total Kjeldahl nitrogen**	**Nitrate+ nitrite**	**Fecal coliform**
Concentrations	Percent decline from 1997 to 2002 (irrigation seasons)					
Sulphur	76	83	66	52	23	76
Granger	79	82	73	64	18	73
Loads & yields						
Sulphur	N/A	85	71	55	43	80
Granger	N/A	86	78	65	37	76

In the Lower Yakima River Suspended Sediment TMDL, the Department of Ecology established a water quality goal of 25 NTU (90^{th} percentile) at the drain mouths by 2002. Sulphur Creek Wasteway met the goal by 2000. Granger Drain made substantial progress but did not meet the goal.

Water quality improvements varied among sub-basins and among years. However, this variability did not correspond with varying implementation rates of government-funded best management practices (BMPs). Widespread but untracked privately-funded BMP implementation may have confounded attempts to quantify the relationship.

These dramatic improvements in water quality took significant effort, including: (1) highly motivated private landowners, primarily agricultural producers; (2) public funding of over $7 million in cost-share and $6 million in low-interest loans throughout the lower Yakima Valley; (3) private funding of roughly $7 million to match the cost-share and $6 million to repay the loans; (4) years of effort by agency staff in identifying concerns, providing technical assistance, and finding funding for landowners to implement BMPs; and (5) active, locally-led enforcement.

The improvements in water quality reflect a major conservation success story. Soil erosion from irrigated cropland is no longer the dominant resource concern it has been for decades in these two watersheds.

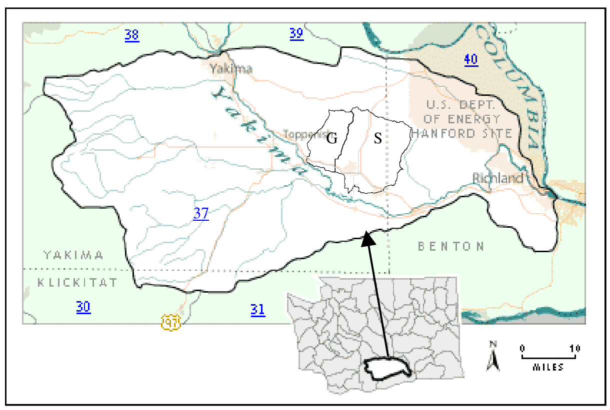
Introduction

Setting

Sulphur Creek Wasteway and Granger Drain are major irrigation return drains to the Yakima River in the southern part of Yakima County and western part of Benton County in south-central Washington (Figure 1). Irrigation return drains are designed and managed to remove excess surface water and shallow groundwater from irrigated cropland. During the summer, water in the lower Yakima River consists largely of water from irrigation return drains.[1] Thus, the water quality of the drains has a significant impact on the water quality of the Yakima River. Historically, Sulphur Creek Wasteway and Granger Drain have been major contributors of various pollutants to the Yakima River.[1,2] In recent years, local, state, and federal agencies and private landowners have intensified efforts to improve water quality through implementation of agricultural best management practices (BMPs). This report summarizes water quality conditions of Sulphur Creek Wasteway and Granger Drain from 1997 to 2002 and identifies concurrent changes in soil and water conservation practices on agricultural lands.

For simplicity, 'Sulphur Creek Wasteway Watershed' and 'Granger Drain Watershed' will be referred to as 'Sulphur Watershed' and 'Granger Watershed.'

Figure 1. Location of Granger (G) and (S) Sulphur watersheds within the lower Yakima River Basin (Water Resource Inventory Area 37) of Washington State.



Watershed characteristics

Sulphur and Granger watersheds both consist of non-irrigated rangeland, irrigated cropland, and minor urban areas. Both watersheds are predominantly rural, although Sunnyside (population 13,905) and a portion of Grandview (population 8,377) are within the Sulphur Watershed, and portions of the Town of Granger (population 2,350)[3] are within the Granger Watershed.

The area is semi-arid, with a mean annual precipitation at Sunnyside of 7.3 inches[4] from 1971 to 2000. Intensive agriculture is possible only due to an extensive irrigation infrastructure.

The ridges of the Rattlesnake Mountains at elevations of 2500-3000 feet form the northern boundary of both watersheds and are managed as rangeland. Range continues five to six miles down-slope to elevations of 1200 to 1300 feet, where irrigation begins and continues for the last six to nine miles of each watershed before reaching the Yakima River at 650 to 700 feet.

To relate land-use characteristics and conservation practices to changes in water quality this report focuses solely on the irrigated portions of the watershed. Due to low rainfall, the range area is not considered a significant source of runoff or shallow groundwater and thus is not a significant influence on the water quality of the irrigation return drains. There are no perennial streams in the range areas of these watersheds.

Milk and commercial crops are the major commodities produced in these watersheds, including irrigated pasture, silage corn, alfalfa, grapes, and apples. In 2002, there were 23 dairies within Granger Watershed and 24 dairies and two large feedlots within Sulphur Watershed.

The predominant soil type in both watersheds is silt loam. Soils are generally very deep and well drained with small areas of somewhat poorly drained soils near Outlook.[5] Within irrigated areas, slopes typically range from one to eight percent.

Sulphur Watershed is 161 square miles and Granger is 62 square miles in size. Of the Sulphur Watershed, 48% is irrigated (49,806 acres or 78 square miles) and 66% of Granger Watershed is irrigated (26,100 acres or 41 square miles). A few of the sub-drains in each of the watersheds discharge into the Sunnyside Canal instead of continuing down to either Granger Drain or Sulphur Creek Wasteway. The surface water runoff from these acres minimally influences the water quality of Granger Drain and Sulphur Creek Wasteway during the irrigation season. The irrigated portions that primarily influence water quality, termed 'surface runoff areas' for this report, account for 35% of Sulphur Watershed (35,526 acres or 56 square miles) and 33% of Granger Watershed (12,962 acres or 20 square miles). The length of Granger Drain and its major sub-drains is approximately 41 miles, the same approximate length as the sum of Sulphur Creek Wasteway and its major sub-drains.[i]

One significant difference between Sulphur Creek Wasteway and Granger Drain is that Sulphur Creek Wasteway receives major operational spills from both Roza and Sunnyside canals, while Granger Drain receives only minor spills from laterals and individual deliveries. Spill water is unused canal water, typically low in suspended sediment, nutrient, and bacteria concentrations.

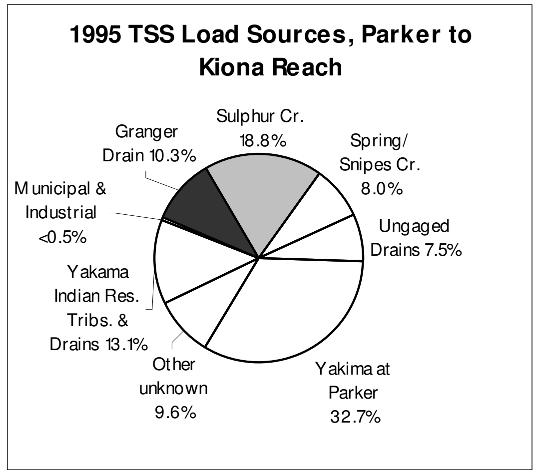
Focus of attention

In recent years, these two watersheds have been the focus of attention of several agencies and many residents as demonstrated by two Total Maximum Daily Loads (TMDLs), third-party lawsuits, and numerous water quality studies by a variety of agencies. Total Maximum Daily Loads are water quality improvement plans developed by the Department of Ecology for surface waters in Washington State that do not meet state water quality standards.

[i] Distance estimates were based on a GIS layer developed by Yakima County, Geographic Information Services Department, and included drains managed jointly by the Sunnyside Division and the Roza Irrigation District plus a large secondary drain, DR 2, within Granger Watershed.

In 1998, the Lower Yakima Suspended Sediment TMDL was adopted to address concerns about DDT and turbidity in the lower Yakima River. The TMDL identified Sulphur Creek Wasteway and Granger Drain as two of the largest sources of suspended sediment (as measured by total suspended solids, TSS) to the lower Yakima River[2] (Figure 2). The TMDL concluded that suspended sediment concentrations in Sulphur Creek Wasteway needed to be reduced by 74% and Granger Drain by 93%[2] from 1995 levels to meet two of the TMDL goals: (1) non-detectable DDT levels in water and fish; and (2) turbidity of 25 NTU or less in 90% of water samples (90th percentile) from fish-bearing drains and sub-drains.

Figure 2. Sources of total suspended solids (TSS) to the Yakima River, 1995.



In 1997, ten lawsuits filed against local dairies by a nonprofit group, the Community Association for Restoration of the Environment (CARE), heightened concerns and awareness of dairy owners of the role that public scrutiny can take in implementing the Clean Water Act through third-party lawsuits. The Clean Water Act is the primary federal law regulating our nation's surface waters. In Washington State, the Department of Ecology is delegated to act in lieu of the Environmental Protection Agency to implement the Clean Water Act.

In 2002, the Granger Drain Fecal Coliform Bacteria TMDL was finalized, addressing fecal coliform concentrations within Granger Drain. This TMDL set targets based on the scheduled progress of the suspended sediment TMDL, with a goal of meeting the state's Class A fecal coliform standard by 2012.[6]

Water quality monitoring within Sulphur or Granger watersheds has been conducted over various time periods by the U.S. Geological Survey, Washington State Department of Ecology, Roza-Sunnyside Board of Joint Control, South Yakima Conservation District, and CH_2M Hill, a consulting firm.

Local efforts to improve surface water quality through improved conservation practices

This report focused on analyzing changes from 1997 to 2002 because data were available on water quality and BMP implementation rates during these years. However, conservation practices and water quality have been improving for many years. Practices such as conservation tillage, land leveling, filter strips, irrigation water management, and converting rill to sprinkler or drip irrigation were implemented voluntarily by landowners through projects such as the South Yakima Model Implementation Project[7] (1978-1982). A key change occurred in the mid-1980's when the Roza Irrigation District, working with other agencies, piped miles of irrigation laterals, providing pressurized water for growers, eliminating the need for an on-farm pump, which in turn provided incentive for growers to convert thousands of acres from rill to sprinkler irrigation. In the 1970's and 1980's, agriculture generally had higher net profits, so many landowners were able to upgrade their systems without public funding.[8]

To provide a reference point to past water quality conditions in these watersheds, water quality data from 1974 were compared against more recent data from the Roza-Sunnyside Board of Joint Control (RSBOJC). The 1974 data were collected by CH_2M Hill[9], which sampled the Sulphur Watershed twice monthly during the 1974 irrigation season at several of the same locations currently used by RSBOJC. Concentrations of suspended sediment, phosphorus, and fecal coliform in the sub-drains and at the mouth generally decreased by approximately half to two-thirds during the 26 years from 1974 to 1999 (Figure 3) and then decreased by approximately half again during the four years from 1999 to 2002. Concentrations of total nitrogen were more variable, increasing in three sub-drains, decreasing in one sub-basin, and comparable at the mouth between 1974 and 1999. Discharge at the mouth in 1974 was comparable to 1997.

Since 1997, efforts to improve water quality of return drains and the Yakima River by improving conservation practices were so numerous that they are beyond the scope of this report to summarize. Only brief highlights are listed below to give an idea of the nature, scope, and diversity of the efforts. The Yakima River Watershed Plan by the Yakima River Basin Watershed Planning Unit and Tri-County Water Resources Agency[10] provides a more comprehensive listing of projects and programs.

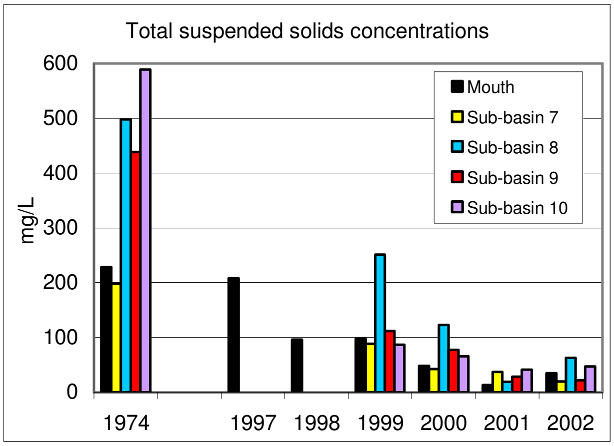
Natural Resources Conservation Service (NRCS)

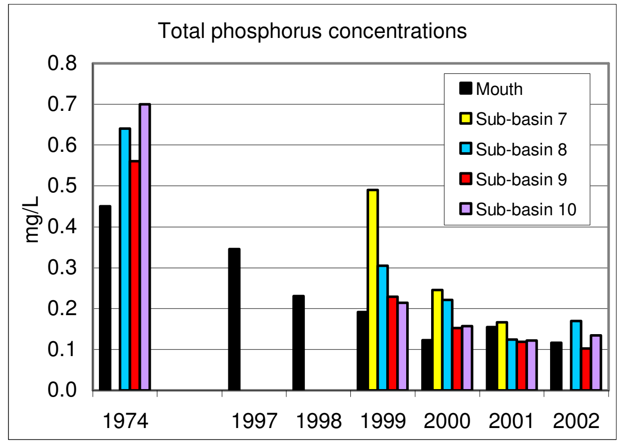
In 1997, NRCS formed a Geographic Priority Area (GPA) for the irrigated portions of Yakima and Benton counties. From 1997 to 2002, participating landowners within the GPA received $4.7 million in cost-share funds through the Environmental Quality Incentives Program (EQIP), improving 9,988 acres. Nearly all of the projects funded by EQIP during these years were conversions from rill irrigation to sprinkler or drip irrigation systems. Many of these projects were within the Granger or Sulphur watersheds.

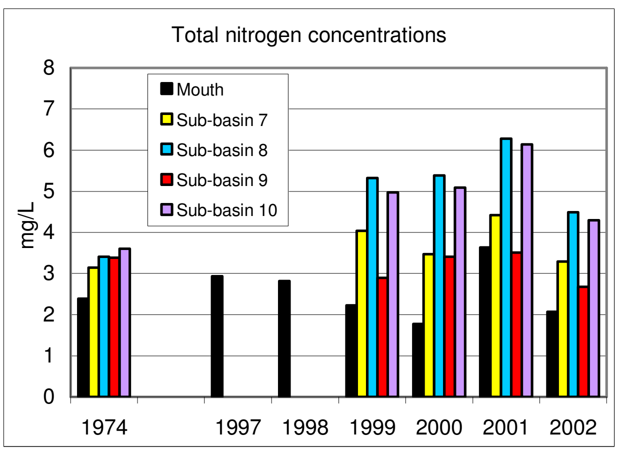
Roza-Sunnyside Board of Joint Control (RSBOJC)

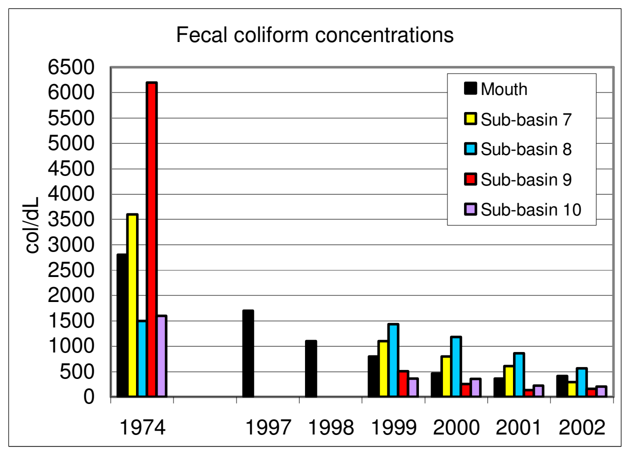
RSBOJC began a locally-led enforcement policy to reduce turbid runoff from farms in 1999. Growers with highly turbid runoff from their fields were sent warning letters asking the grower to reduce the turbidity of their runoff. If repeated occurrences of turbid runoff were documented, the irrigation district reduced the water supply to that grower. RSBOJC also has conducted water quality monitoring of Granger Drain and Sulphur Creek Wasteway since 1997. In 1999, RSBOJC received a $10 million loan from the Department of Ecology's State Revolving Loan Fund for low-interest loans to landowners converting from rill to sprinkler or drip irrigation systems. The loan program began in 2000 and loaned $4.6 million through 2002, improving 7,344 acres.

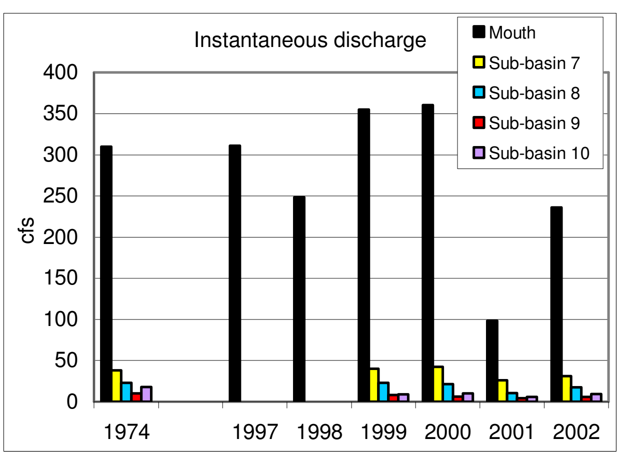
Figure 3. Total suspended solids, total phophorus, total nitrogen (nitrate+nitrite plus total Kjeldahl nitrogen), and fecal coliform concentrations, and instantaneous discharge, Sulphur Watershed, irrigation seasons, CH2M Hill 1974 data (averages) and Roza-Sunnyside Board of Joint Control 1997 to 2002 data (medians).











Roza Irrigation District and Sunnyside Division

The Roza Irrigation District and the Sunnyside Division continued to upgrade the irrigation delivery systems by enclosing lateral canals in pipes during these years. In addition, the Roza Irrigation District loaned $2 million to landowners converting from rill to sprinkler or drip irrigation systems in 1999 and 2000. Over 2,200 acres were converted, primarily in Benton County.

South Yakima Conservation District (SYCD)

From 1997 to 2002, as lead entity in a regional cluster of conservation districts, SYCD provided technical assistance and distributed over $2 million of cost-share funds from the Washington State Conservation Commission (WCC) to 80 dairies within a 5-county area (Yakima, Benton, Franklin, Grant, and Skamania) for BMPs such as lining manure lagoons and improved manure transfer facilities. Forty-seven of these dairies were located in Granger and Sulphur watersheds. In addition, within SYCD, over $540,000 from WCC was provided as cost-share for irrigation BMP projects to growers during these years.

Through grants from the Department of Ecology and Conservation Commission, SYCD also conducted a variety of water quality projects, including: (1) focused BMP implementation projects in Granger and Sulphur watersheds; (2) water quality studies; (3) evaluation of two innovative alternatives for treating water in irrigation return drains (i.e., Battelle's In-Streem™ treatment technology and using poplar trees as biotreatment); and (4) pasture improvement workshops and tours in cooperation with WSU-Cooperative Extension.

Washington State Department of Ecology

The Department of Ecology developed two TMDLs, provided half-time staffing for 1½ years to assist RSBOJC in implementing their local enforcement policy, directly contacted landowners to encourage conservation practices, and conducted an irrigation workshop with Dr. Charles Burt, California Polytechnic State University.

Washington State University – Cooperative Extension (WSU)

WSU Cooperative Extension in Prosser led a focused BMP implementation effort for growers within the Granger Watershed from 1991 to 1997 that included workshops, outreach, and demonstrations of PAM applications. WSU also provided on-going technical support to growers and agencies on dairy nutrient management practices, soil fertility, crop-specific nutrient and irrigation guidelines, pasture management, and a variety of other agricultural issues.

From 1997 to 2002, the three largest sources of public funding (EQIP cost-share, WCC cost-share, and RSBOJC loans) assisted landowners in implementing BMPs on almost 13,000 acres within SYCD. Of these funded BMPs, 58% were within the Granger and Sulphur watersheds even though these watersheds account for only 23% of the 312,798 irrigated acres[11] within SYCD. The relatively high participation in these funding programs by landowners within Sulphur and Granger is one reflection of the intensity of effort in these watersheds.

Water quality results

The results discussed in the following section are based entirely on water quality data collected by RSBOJC. Because of the high quality data from RSBOJC, SYCD has not needed to develop an ambient water quality sampling program.

RSBOJC water quality sampling methods

RSBOJC generally sampled Granger Drain, Sulphur Creek Wasteway, and their major sub-drains every two weeks during the irrigation season (early April to mid-October) and monthly during the non-irrigation season. Nutrient and sediment samples were obtained using an equal-width-depth increment sampler following USGS protocol. Fecal coliform samples were obtained using a grab sampling technique (the equal-width-depth sampler cannot be sterilized as needed when sampling for bacteria). Discharge was measured using a flume at several sites. At the sites with only a staff gage, discharge was measured using a hand-held flow meter. Rating curves were established for selected sites.

RSBOJC analyzed for fecal coliform, turbidity, and suspended sediment in their in-house, state-accredited laboratory. Nutrient samples were shipped overnight to the Bureau of Reclamation's laboratory in Boise, Idaho and analyzed for total phosphorus, nitrate+ nitrite, and total Kjeldahl nitrogen. Most analyses were provided at no cost to RSBOJC by the Bureau of Reclamation, as a cooperating agency providing technical assistance.

Terms

The types of data gathered by RSBOJC discussed in this report are the following:

- **Discharge**. Rate of water flow in cubic feet per second (cfs).
- **Total suspended solids**. Sediment suspended in water, measured in milligrams per liter (mg/L), which equals parts-per-million (ppm).
- **Total phosphorus**. Dissolved and sediment-bound phosphorus (mg/L).
- **Total Kjeldahl nitrogen**. Organic nitrogen plus ammonia, as nitrogen (mg/L).
- **Nitrate+nitrite**. Nitrogen in oxidized (nitrate) and reduced (nitrite) forms, as nitrogen (mg/L).
- **Fecal coliform**. Indicator bacteria from the gut of warm-blooded animals, used to indicate the potential presence of pathogens, measured in colony-forming units per deciliter of water (cfu/dL);
- **Total dissolved solids**. Dissolved ions usually as salts (mg/L); and
- **Specific conductance**. Ability of water to carry an electrical current, expressed in microsiemens per centimeter (uS/cm). Siemens are the reciprocal of ohms.

The measurements described in this report include the following:

- **Concentration**. The amount of material in a water sample on a per volume basis, such as milligrams per liter.

- **Load.** The amount of substance (constituent) being discharged from a source, often calculated on a daily basis, such as pounds per day of phosphorus.

- **Median values**. The value for which half of the values are smaller and half of the values are larger. Medians are usually similar to averages but are less distorted by extreme values. Median values often describe the central tendency of a data set, or the value most commonly expected in a water sample on any given day. Medians are the primary descriptor of the data in this report, except when values are compared against regulatory standards, for example, the geometric mean of fecal coliform concentrations.

- **Yield**. The pounds *per acre* per day of a given constituent from a drainage area, or in the case of discharge, the volume of water per acre per day from a drainage area. Yield is useful because it eliminates differences in loads solely due to differences in drainage size. For constituents transported primarily via surface runoff (suspended sediment, phosphorus, total Kjeldahl nitrogen, and fecal coliform), the area used to calculate yield included only those irrigated acres from which surface runoff contributed to the drain being monitored. For constituents transported primarily through groundwater (nitrates and total dissolved solids), the area used to calculate yield included all the irrigated acres within each drainage area.

Data from the irrigation season are discussed first, followed by a brief discussion of the non-irrigation season data at the end of the section.

Irrigation season

General trends and observations

Downward trends of median concentrations, loads, and yield.
Median concentrations, loads, and yields of suspended sediment, total Kjeldahl nitrogen, nitrate, total phosphorus, and fecal coliform declined in both watersheds, as did turbidity (Table 1).

Table 1. Declines in median concentrations, loads, and yield from Sulphur Creek Wasteway and Granger Drain, 1997 to 2002 irrigation seasons.

	Turbidity	**Total suspended solids**	**Total phosphorus**	**Total Kjeldahl nitrogen**	**Nitrate+ nitrite**	**Fecal coliforms**
Concentrations	Percent decline from 1997 to 2002					
Sulphur	76	83	66	52	23	76
Granger	79	82	73	64	18	73
Loads & yields						
Sulphur	N/A	85	71	55	43	80
Granger	N/A	86	78	65	37	76

The median instantaneous discharge from the drains also decreased between 1997 and 2002, by 24 percent in Sulphur Creek Wasteway and 18 percent in Granger Drain.

The declines in loads in Table 1 are identical to declines in yields because yield is just the load divided by the number of acres in the drainage area.

Trend analysis (seasonal Kendall trend test) was conducted for all constituents from 1997 to 2002 for water samples collected from the mouths of the drains during the irrigation season. Downward trends were statistically significant ($p<0.01$) for concentrations of suspended sediment, total phosphorus, total Kjeldahl nitrogen, and fecal coliform in both drains. There was no evidence of a statistically significant downward trend for nitrate+ nitrite in either Sulphur Creek Wasteway ($p=0.18$) or Granger Drain ($p=0.46$); while nitrate concentrations were lower in 2002 than 1997, in the intervening years there were also increases in concentrations.

In general, the rates of declines of suspended sediment, phosphorus, total Kjeldahl nitrogen, and fecal coliform concentrations were steepest from 1997 to 2000 then slowed from 2000 to 2002.

Decreasing range of values
The range of concentrations of suspended sediment, phosphorus, total Kjeldahl nitrogen, and fecal coliform (Figures 4 and 5) also decreased, especially in Granger Drain. Systematic decreases of the upper values of the constituents primarily transported by surface water runoff are best explained by less frequent discharges of concentrated runoff into the drains. Constituents primarily transported by surface water runoff include suspended sediment, total Kjeldahl nitrogen, the portion of phosphorus bound to sediment, and fecal coliform.

Drought
During the drought of 2001, the Roza Irrigation District, a junior water right holder, received only 37% of its normal water supply. The Sunnyside Division, a senior water right holder, received 85% of its normal water supply. Both Sulphur and Granger watersheds are serviced by both irrigation districts. The effect of the drought was seen in reduced discharge and loads of most constituents from the mouths of both drains (see Figures 10, 13B&F, 14B&F, 15B&F, and 16B&F).

Sulphur vs. Granger
Turbidity (Figure 11) and concentrations of suspended sediment, total phosphorus, total Kjeldahl nitrogen, and fecal coliform (Figures 4 and 5) were generally less in Sulphur Creek Wasteway than in Granger Drain. This difference is due, in part, to Sulphur Creek Wasteway receiving large volumes of unused water (called "spill" water) from the canal system. Spill water has relatively low concentrations of these constituents, diluting the drain water. However, even the sub-drains within Sulphur Watershed – which receive minimal amounts of dilute spill water – had lower 75th and 90th percentile concentrations of most constituents than the sub-drains in Granger Watershed (Figure 6). Despite the lower concentrations in Sulphur Creek Wasteway, loads were generally much higher in

Figure 4. Total suspended solids and total phosphorus concentrations in Sulphur Creek Wasteway and Granger Drain, 1997 to 2002 irrigation seasons.

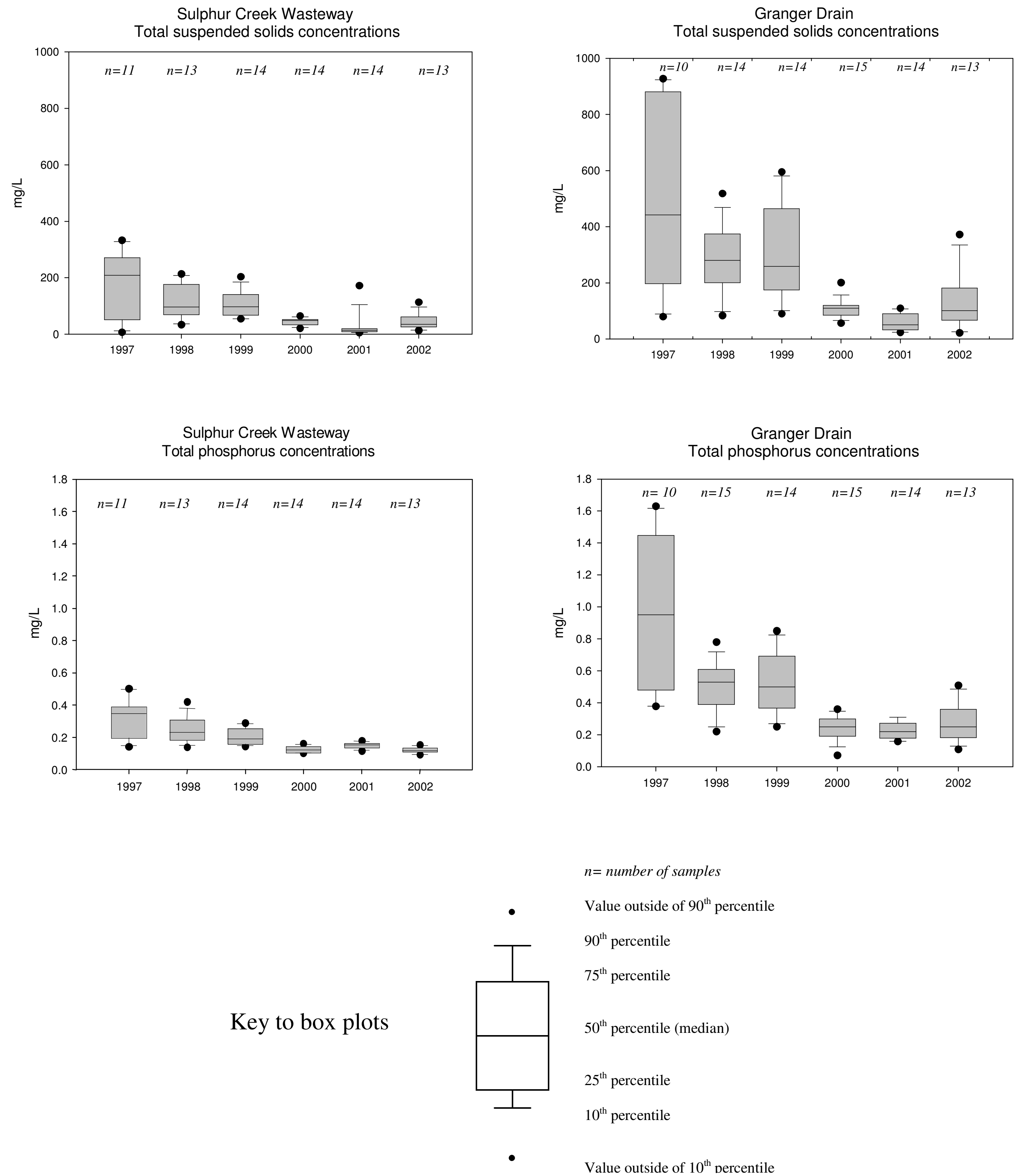


Figure 5. Nitrate+nitrite, total Kjeldahl nitrogen, and fecal coliform concentrations in Sulphur Creek Wasteway and Granger Drain, 1997 to 2002 irrigation seasons.

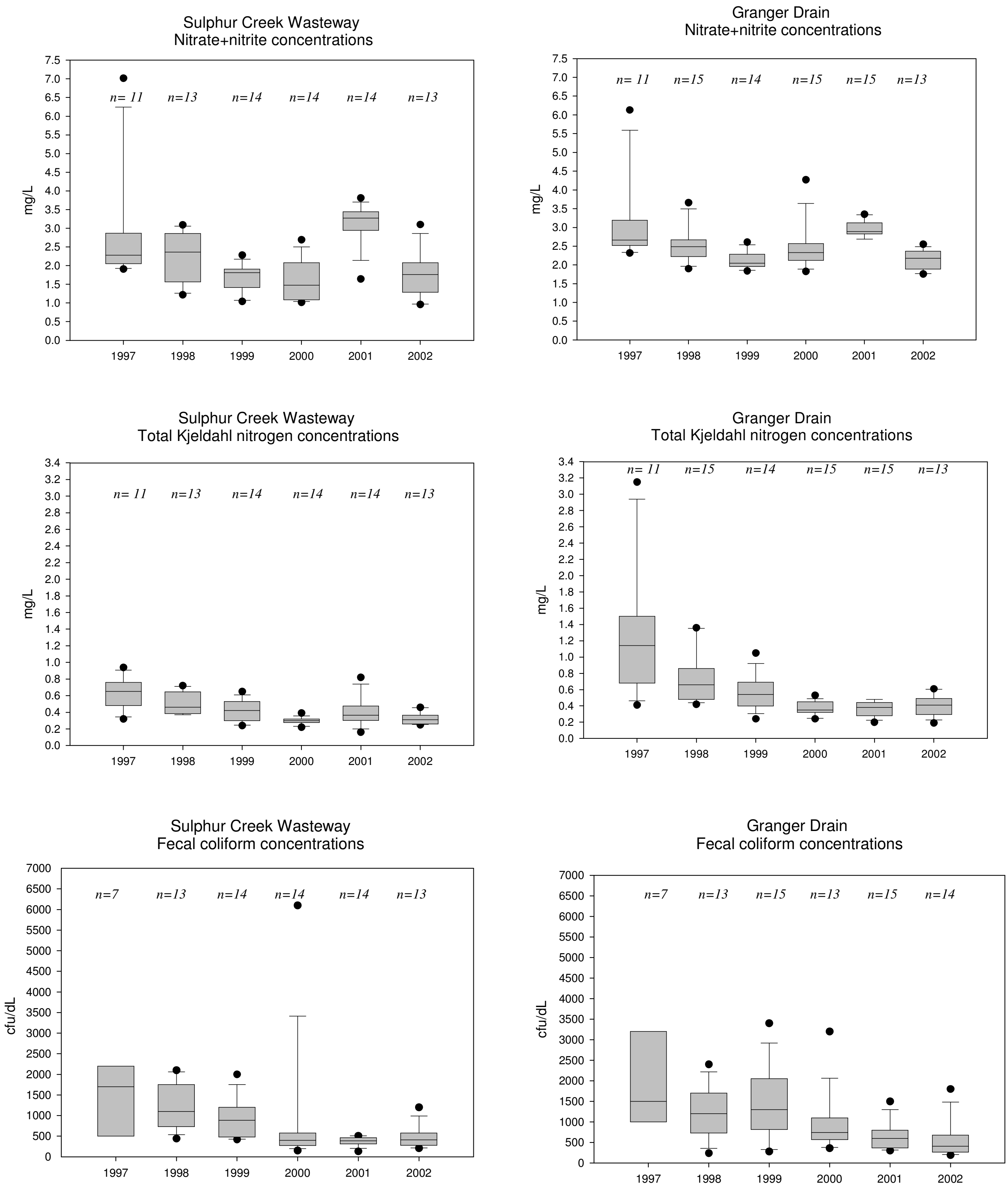
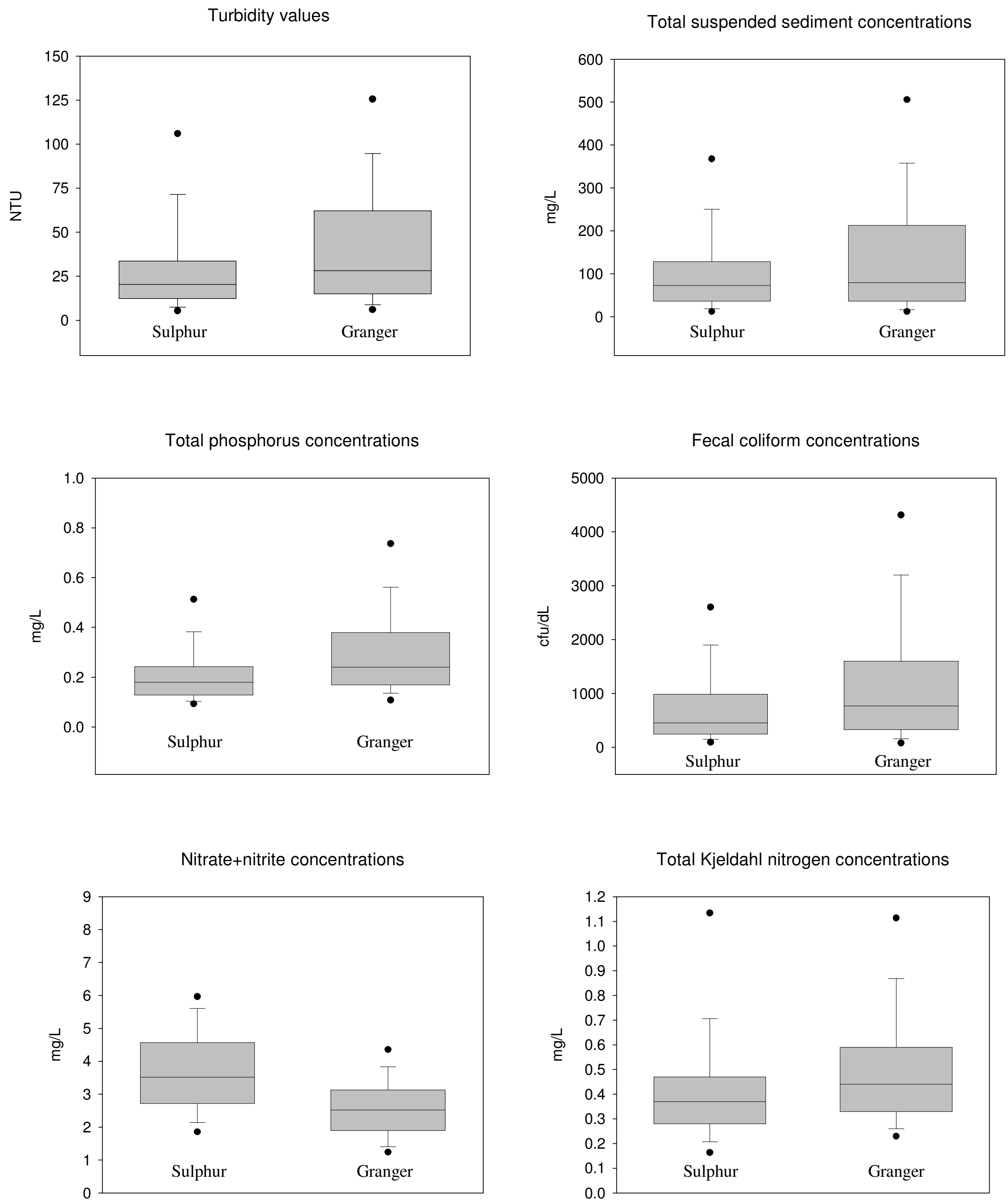


Figure 6. Concentrations of selected constitutents, Granger and Sulphur sub-basins, 1999 to 2002 irrigation seasons.

● indicates 5th and 95th percentile



the wasteway than in Granger Drain because the sheer volume of water was so much greater in the wasteway. The variability of concentrations of most constituents was generally higher in Granger than Sulphur (Figures 4, 5, and 6).

Load balance
The median loads from all sub-basins within a watershed for each irrigation season were summed and compared against loads from the mouths of the drains in the irrigation season. In some years and for some constituents, the loads balanced well; in other years the sum of the sub-basins only accounted for half of the load from the mouths (Figure7).

A portion of the imbalance could be attributed to estimated contributions from the unmonitored portions of the watersheds. Loads from the unmonitored portions of the watersheds were estimated by applying the median yield from all monitored sub-basins to the acres not captured by current monitoring efforts. In Granger Watershed, the extrapolated load from the unmonitored portions is over-estimated since the irrigated acres south of I-82 were included but only discharge intermittently to Granger Drain.

In Sulphur Watershed, additional portions of the imbalance could be attributed to contributions from the Sunnyside urban area (except for suspended sediment) and canal spills. The urban influence was estimated by subtracting the load from a site upstream of Sunnyside from the load downstream of Sunnyside in the same drain. The upstream site was not monitored in 2002 so the urban influence could be estimated only for 1999 to 2001. Suspended sediment loads decreased between the monitoring site located upstream of Sunnyside and downstream of the city, indicating deposition of the suspended sediment. Loads of other constituents increased by varying amounts. Data on canal spills were only available for 1999 and 2000. While the concentrations of the studied constituents were low in the canal spill water, the sheer volume of water spilled resulted in loads large enough to need accounting for when balancing the various contributions.

<u>Specific parameters</u>

Each water quality parameter will be discussed in the following sections in terms of irrigation season concentrations, loads, and yields for sub-basins with active monitoring sites. One monitoring site in Sulphur Watershed was located downstream of where the return drain in sub-basin 5 combines with the return drain in sub-basin 6, so the charts in this report refer to “sub-basins 5 & 6.” Similarly, in Granger Watershed, one monitoring site was located downstream of where drains in sub-basins 1, 2, and 3 combine, so the charts refer to “sub-basins 1,2,3.” Figures 8 and 9 show sub-basin boundaries.

Discharge
Using seasonal changes in discharge volumes as a rough estimator, during the irrigation season about one-third to one-half of the water in Granger Drain was from groundwater and one-half to two-thirds from irrigation-induced runoff. In Sulphur Creek Wasteway, the proportion of groundwater during the irrigation season was about one-sixth to one-quarter of total discharge, reflecting the importance of the spill water.

Figure 7. Load from the mouths, sum of the sub-basins, and other contributions.

Sulphur | **Granger**

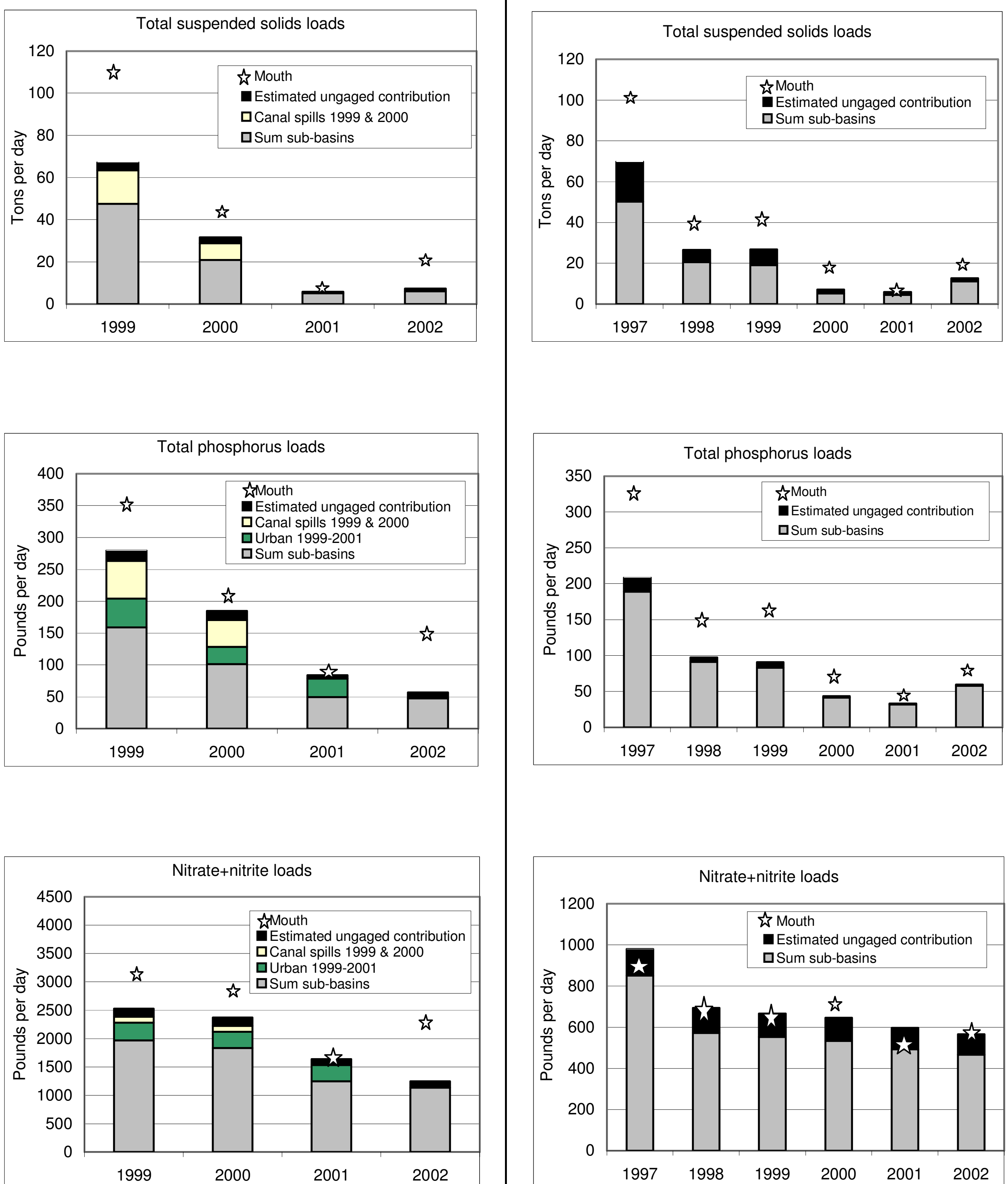
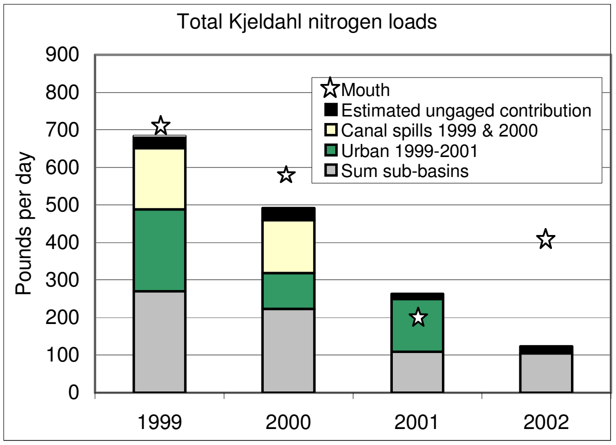
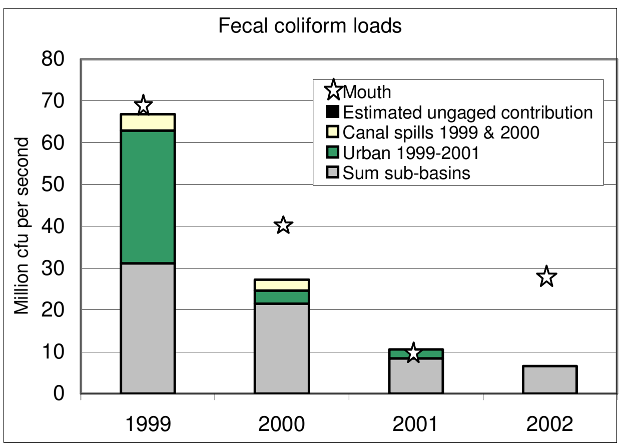
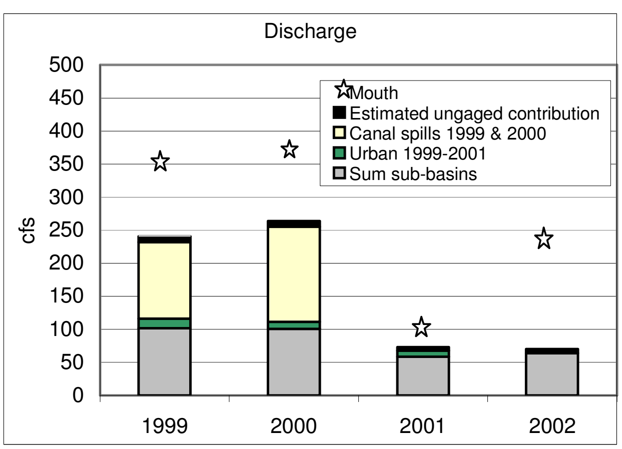


Figure 7 continued. Load from the mouths, sum of the sub-basins, and other contributions.

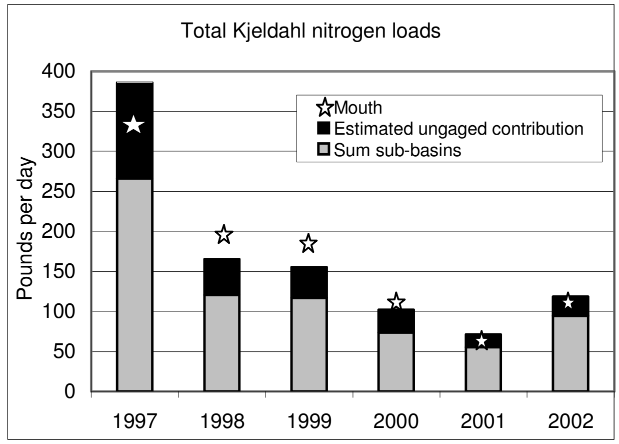
Sulphur

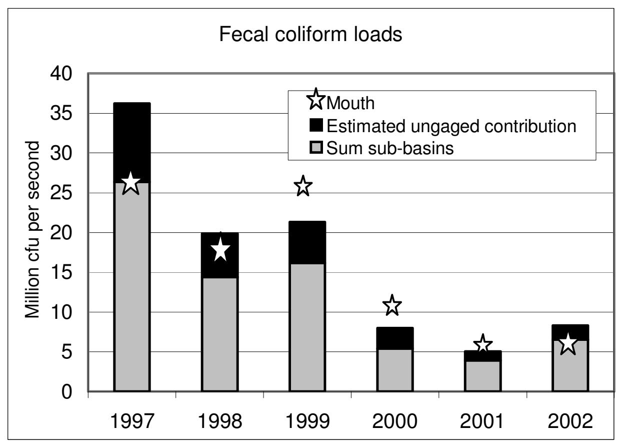






Granger





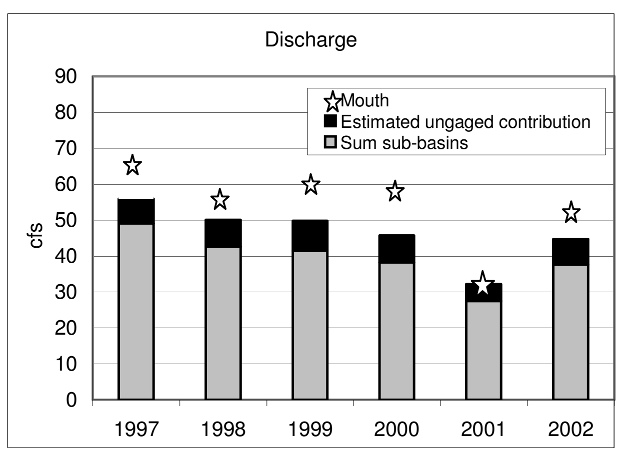


Figure 8. Delineation of Granger sub-basins.

Notes:

Thick, darker sub-basin lines = surface run-off areas
Thin, lighter sub-basin lines = irrigated areas potentially influencing groundwater
JD = Joint Drain, a drain jointly managed by Sunnyside Division and Roza Irrigation District
DR = Drain

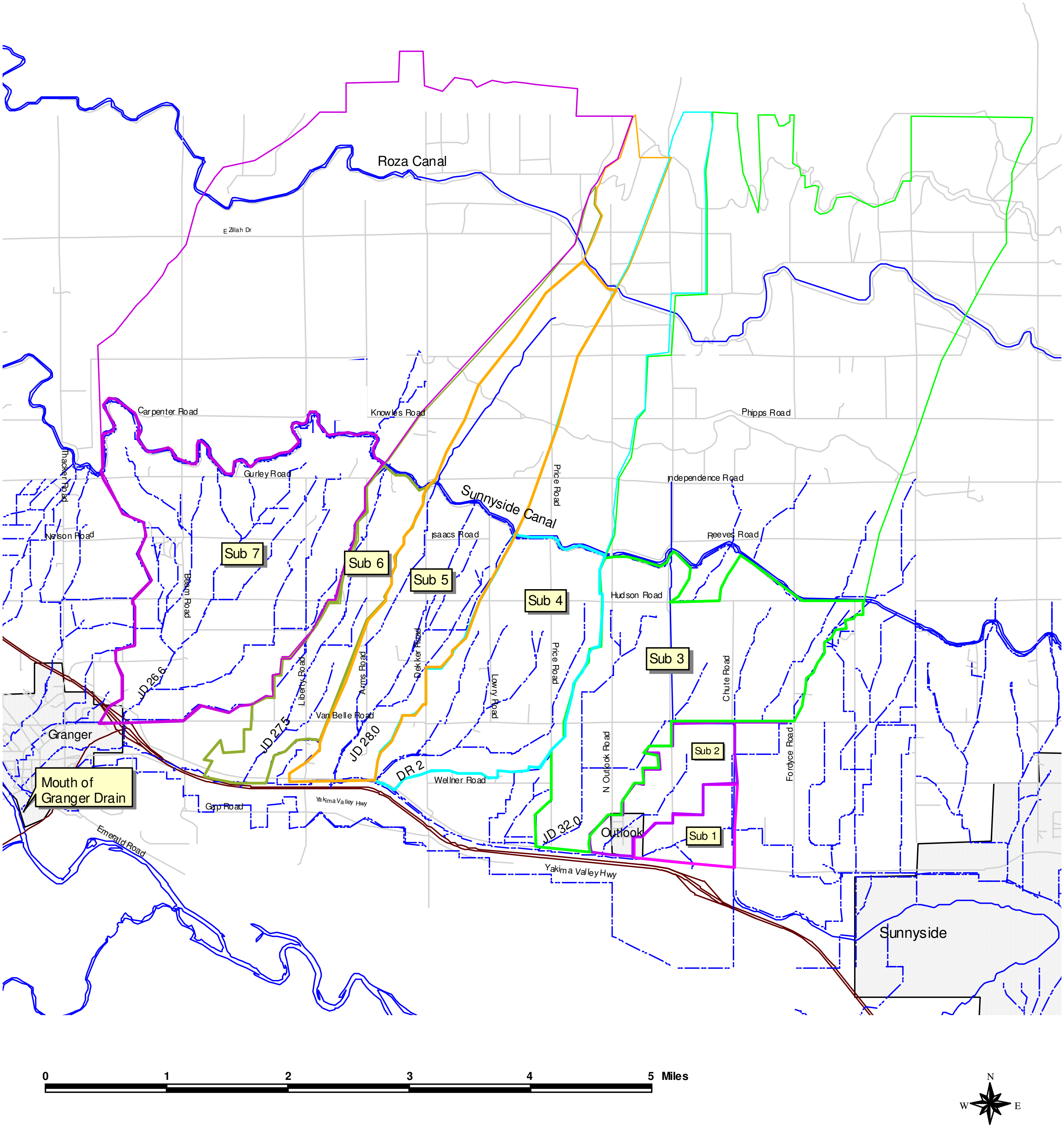
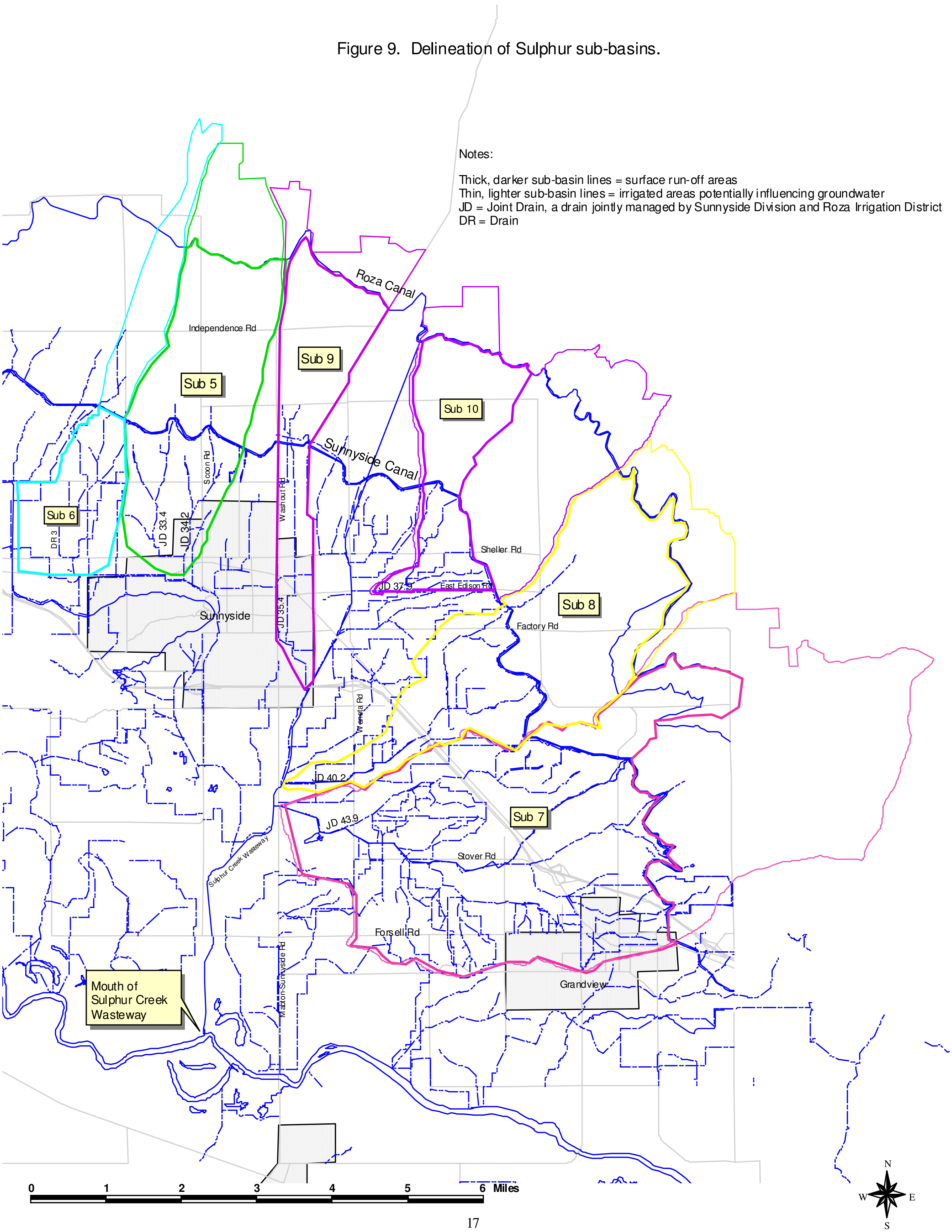


Figure 9. Delineation of Sulphur sub-basins.



Median instantaneous discharge of both drains to the Yakima River declined from 1997 to 2002, as did the median discharge of most of the sub-drains (Figure 10A&E).

The relative ranking of highest-to-lowest discharge rates among sub-basins within both watersheds stayed nearly the same from year to year (Figure 10B&E). For example, the Granger sub-basin with the highest discharge in 1997 stayed highest all six years. This suggests the major factors influencing the differences in discharge rates between sub-basins were more likely permanent physical characteristics such as soil type or slope of the drains rather than variable on-farm practices.

The volume of water yielded (acre-feet of water discharged per acre per irrigation season) from the Sulphur and Granger watersheds also generally declined over these years (Figure 10C&F). The range of declines in yields from the sub-basins was similar in both watersheds. The declines most likely represent improved water conservation, not decreased water availability, since the amount diverted from the Roza and Sunnyside canals remained stable (medians ranged from 1670 to 1855 cfs, and 1145 to 1194 cfs, respectively) during the non-drought years of 1999, 2000, and 2002.

Discharge was not correlated to the concentrations of any water quality constituent, except for nitrate, which was weakly, inversely correlated to discharge from Sulphur Creek Wasteway (Appendix 1).

Turbidity and suspended sediment

Turbidity values and suspended sediment concentrations are often closely related. In these data, turbidity strongly correlated ($r^2 = 0.87$) with suspended sediment concentrations, meaning that 87% of the variability in turbidity values could be explained by variability in suspended sediment concentrations (Appendix 2).

Median turbidity (Figure 11) and suspended sediment concentrations (Figure 13A&E) were lower at the mouth of Sulphur than the mouth of Granger for all six years. Sulphur sub-basins generally had lower values than Granger sub-basins in 2001 and 2002.

The Lower Yakima River Suspended Sediment TMDL set a turbidity goal of 25 NTU (90^{th} percentile value) for the mouth of Sulphur Creek Wasteway and Granger Drain by 2002 and all the sub-drains by 2007. Sulphur Creek Wasteway met the 2002 goal by the year 2000 (Figure 11). Sulphur sub-basins 7 and 9 met the 2007 goal by 2001. Granger Drain did not meet the 2002 goal, nor did any of its sub-basins. The TMDL also set a goal of less than one nanogram per liter concentrations of DDT in surface waters for 2012. When USGS sampled the Yakima River in August 1999, DDT was not detected.[12]

Turbidity values and suspended sediment concentrations and loads would be expected to decline when substantially less water is applied to the land, as seen in the drought of 2001. In drought years, some fields are kept out of production, some fields receive so little water that the irrigation water does not reach the end of the furrow (eliminating runoff but also substantially decreasing production), and there is a general tendency to

Figure 10. Instantaneous discharge and yields of water from irrigation return drains, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.

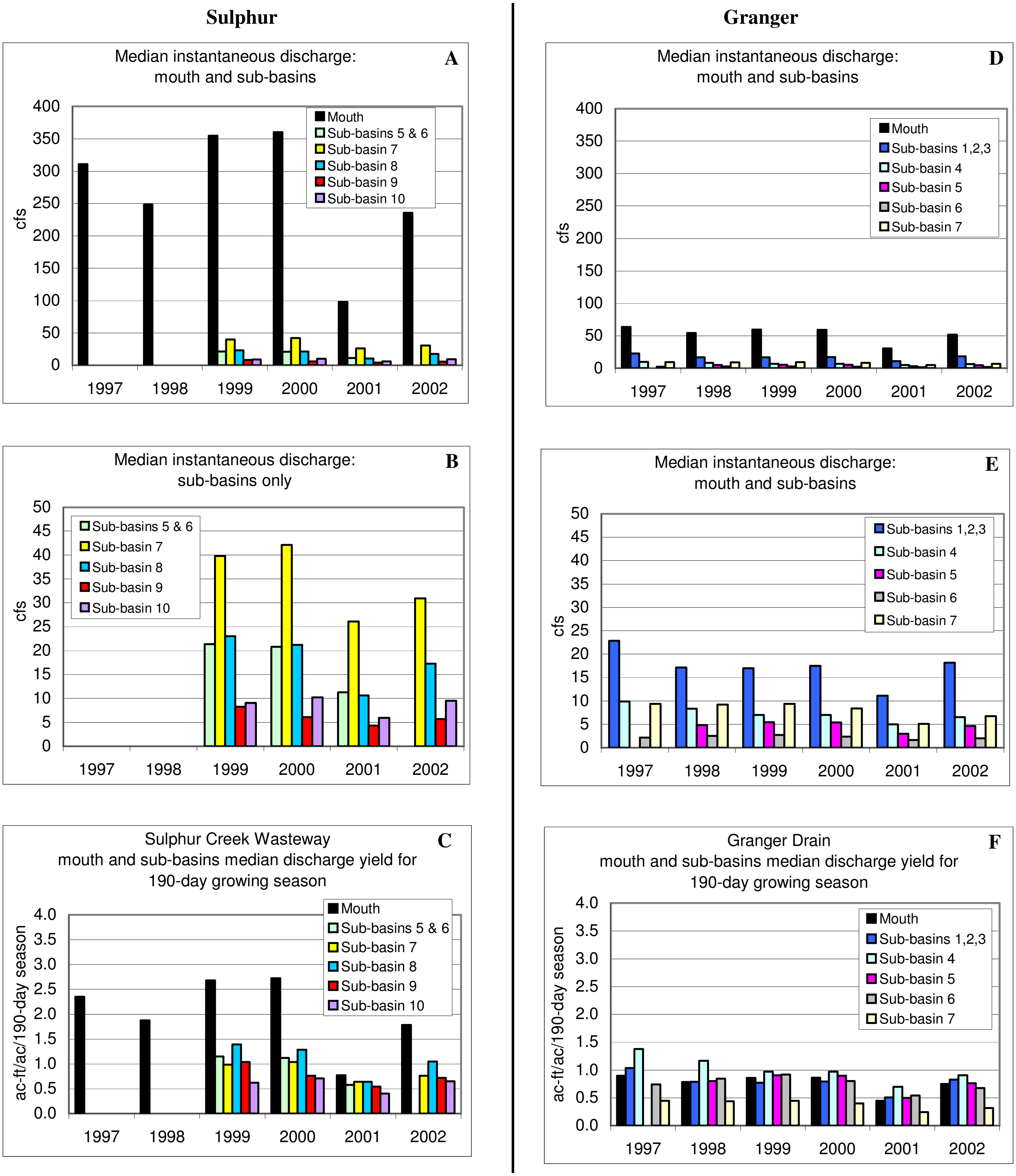
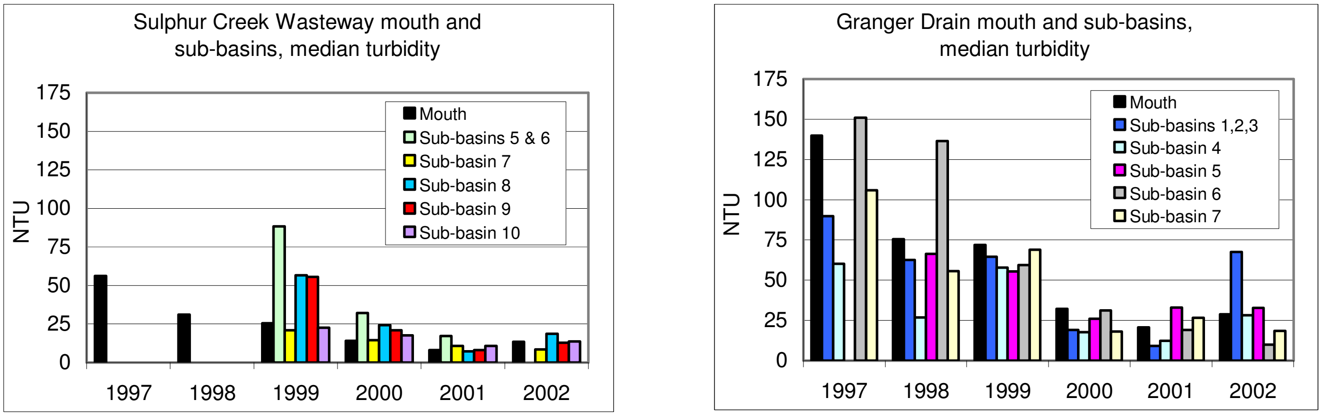


Figure 11. Turbidity: median and 90th percentile values, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.



Note differences in scale between charts of medians, above, and the 90th percentiles, below.

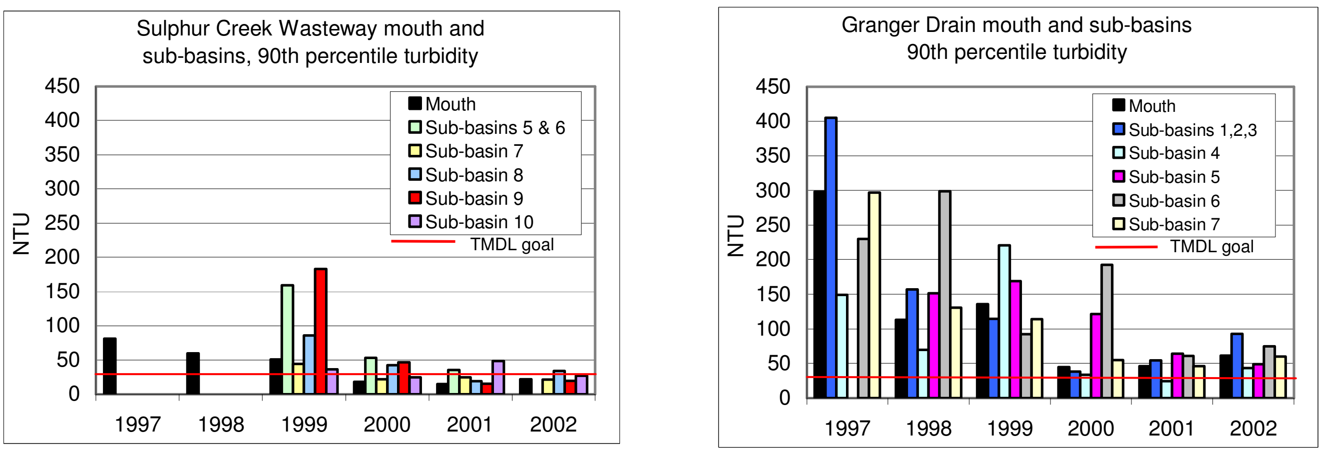
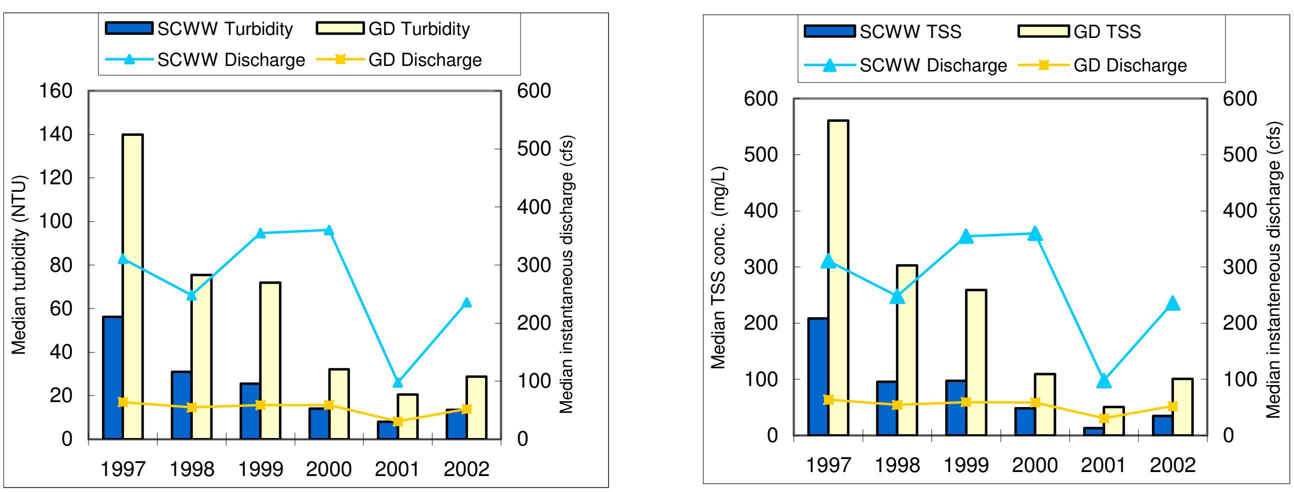


Figure 12. Median turbidity values, total suspended solids concentrations, and instantaneous discharge, Sulphur Creek Wasteway and Granger Drain, 1997 to 2002 irrigation seasons.



use more care in irrigating. So the decreased concentrations and loads seen in 2001 most likely primarily reflect the effect of the drought. In contrast, the declines in turbidity and suspended sediment concentrations between pairs of years with similar discharge -- 1999 vs. 2000 and 1998 vs. 2002 -- in Sulphur Creek Wasteway (Figure 12) suggest reductions in sources of suspended sediment.

No one sub-basin consistently had the highest concentration, load, or yield of suspended sediment (Figure 13). This variability suggests that one of the most important factors influencing suspended sediment concentrations in the drains is also variable, such as changing conservation practices -- not permanent features such as slope or soil type.

Despite the yearly variability among the sub-basins' highest-to-lowest ranking, suspended sediment concentrations in all sub-basins declined during the years studied (Figure 13A&E). These comprehensive declines suggest that a change in transport efficiency of the drains is unlikely to be the primary factor responsible for improvements in water quality, since known factors affecting transport efficiency tend to be intermittent and variable, such as dredging a particular drain or aquatic plant growth, or have remained relatively stable, such as canal diversions (except for the 2001 drought).

Suspended sediment loads have also declined at all sites (Figure 13B&F). Two points shown in Figure 13B&F are essential to understanding these watersheds: (1) the load from Sulphur was much greater than from Granger; and (2) the load from the mouths of either drain was much greater than from any individual sub-basin. Figure 13C&G use a different scale to better show the decreasing loads from the sub-basins.

Yields of suspended sediment were generally comparable between watersheds except in 1997 when the yield from Granger Watershed was nearly double the yield from Sulphur Watershed (Figure 13D&H) and in 2002 when the yield from Granger sub-basins 1,2,3 was much higher than other sub-basins. Yields from each watershed and all sub-basins declined over the years. In most sub-basins, declines were substantial.

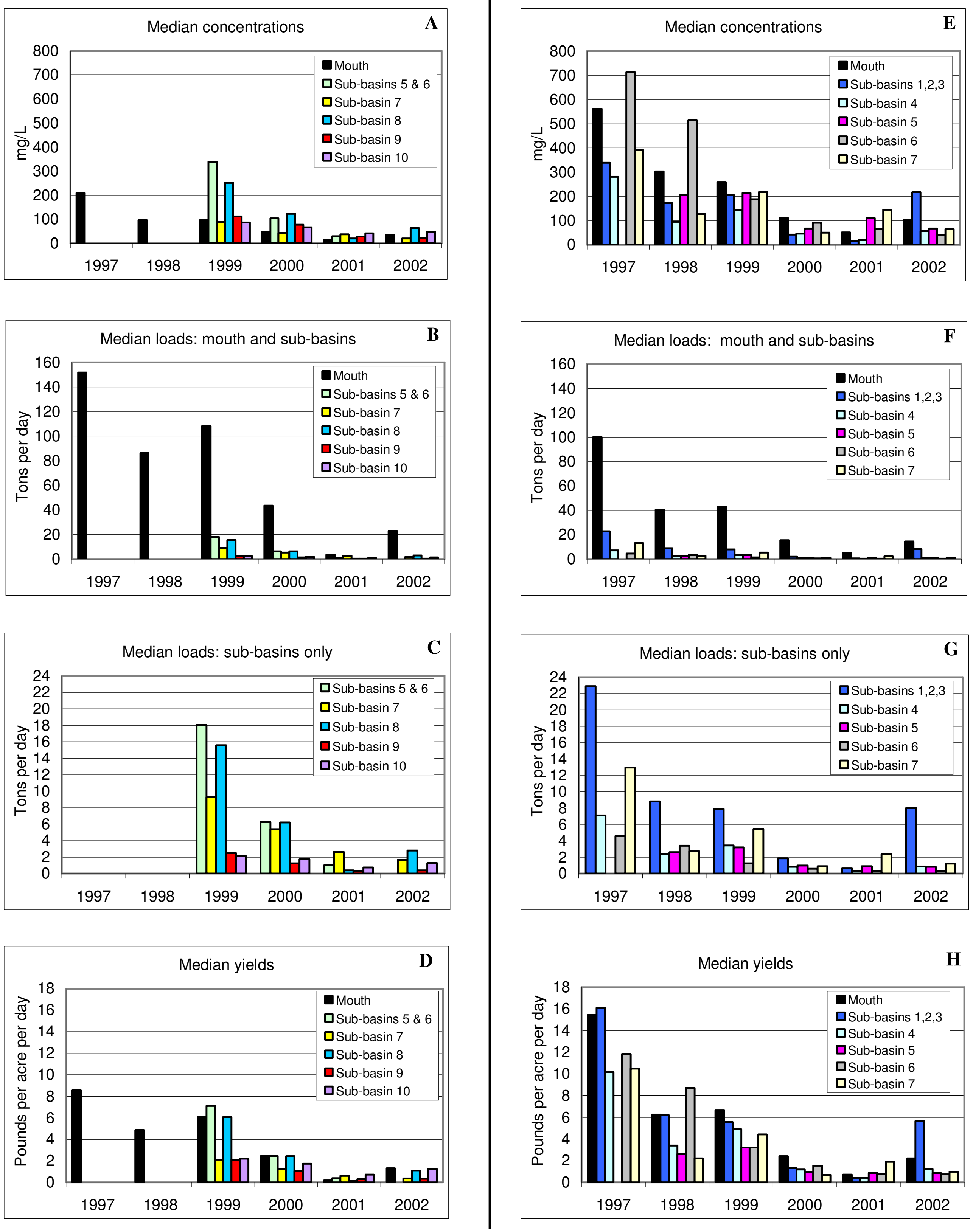
Nutrients

Concentrations, loads, and yields of phosphorus and total Kjeldahl nitrogen (organic nitrogen plus ammonia) declined in both watersheds, although not as dramatically as suspended sediment. Nitrate declines were smaller and in two sub-basins concentrations increased. These results are consistent with our understanding of changes in soil and water conservation practices during these same years. More effort was spent on runoff reduction strategies than on improving nutrient management, except for the relatively small number of dairies (compared to the number of commercial crop growers) implementing nutrient management plans.

RSBOJC had samples analyzed routinely for three types of nutrients: total phosphorus (dissolved phosphorus and phosphorus bound to sediment particles), total Kjeldahl nitrogen (organic nitrogen and ammonia), and nitrate+nitrite (inorganic nitrogen).

Figure 13. Total suspended solids: median concentrations, loads, and yields, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.

Sulphur | **Granger**



Total phosphorus

Of the three types of nutrients analyzed – phosphorus, organic nitrogen, and inorganic nitrogen – phosphorus decreased the most. Phosphorus is more tightly bound to sediment than are nitrogen compounds, so conservation practices that reduce soil erosion should be more effective at reducing phosphorus in surface waters. In the past, phosphorus was thought to bind entirely to sediment particles in surface waters. However, a study of the Yakima River found that only about half of the phosphorus present in the water was bound to sediment.[13] In Sulphur and Granger watersheds, 69% of the variability in phosphorus concentrations was accounted for by the variability in suspended sediment concentrations (Appendix 2) suggesting a very similar but not identical transport mechanism at work. Finally, phosphorus concentrations, loads and yields did not reduce as much as suspended sediment (Table 1).

Median phosphorus concentrations decreased in all sub-basins and at both drain mouths (Figure 14A&E), although variably -- concentrations in a few sub-basins decreased sharply while in other sub-basins concentrations decreased only slightly. Median concentrations in Granger sub-basins were comparable to Sulphur sub-basins (Figure 6).

Phosphorus loads decreased in all sub-basins and at both mouths by varying amounts, in some cases substantially. Phosphorus yield was similar from Sulphur and Granger watersheds, except in 1997 when yield from Granger was much higher than from Sulphur and in 2002 when yield from Granger sub-basins 1,2,3 was unusually high. Yield decreased from both watersheds and all sub-basins over the years.

Nitrate+nitrite

Nitrite is the reduced form of inorganic nitrogen. Other studies have found that nitrite is not a significant component of inorganic nitrogen in the Yakima Basin.[13] So the following discusses only nitrate, the oxidized form of inorganic nitrogen.

Unlike the other constituents measured, nitrate is highly soluble in water, does not bind well to soil particles, and readily leaches into groundwater. Conservation practices intended to primarily reduce soil erosion should have less effect on nitrate concentrations. Indeed, nitrate was the only major constituent that did not have a statistically significant downward concentration trend at the drain mouths during the irrigation season. In the sub-basins, nitrate concentrations were generally quite variable: concentrations in some sub-basins increased in some years, some sub-basins remained nearly constant, while others declined (Figure 15A&E). Nitrate concentrations were higher in 2001 at most sites most likely because of the drought. Less runoff entered the drains, so less dilution of the groundwater occurred.

Nitrate concentrations were similar at the mouths of the two drains but were higher in Sulphur sub-basins 8 and 10 than in Granger or other Sulphur sub-basins. Based on the specific conductance of the drain water, sub-basin 10 may have had a higher proportion of groundwater than the other sub-drains, which could help explain the higher nitrate concentrations. Higher specific conductance generally indicates a higher proportion of

Figure 14. Total phosphorus: median concentrations, loads, and yields, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.

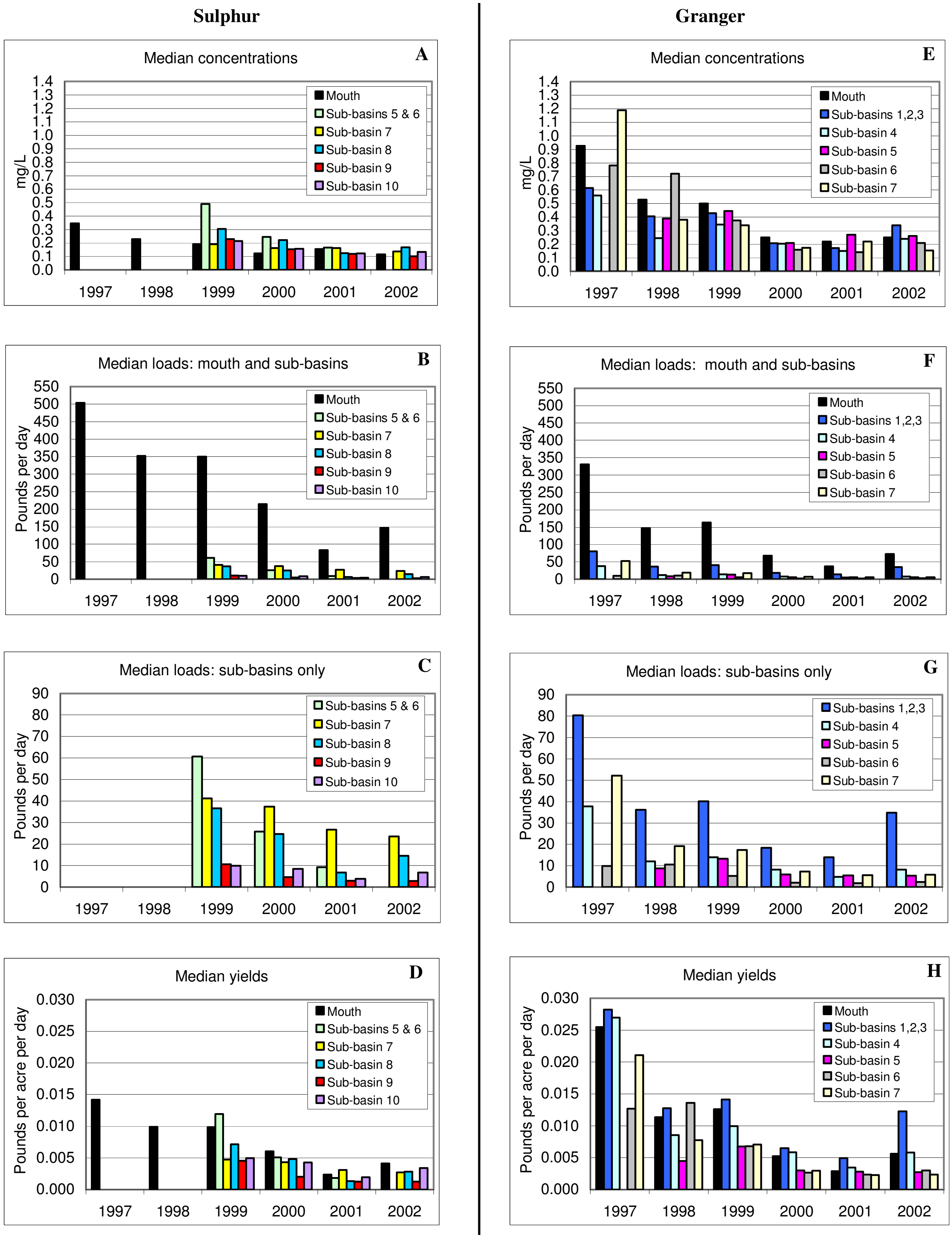
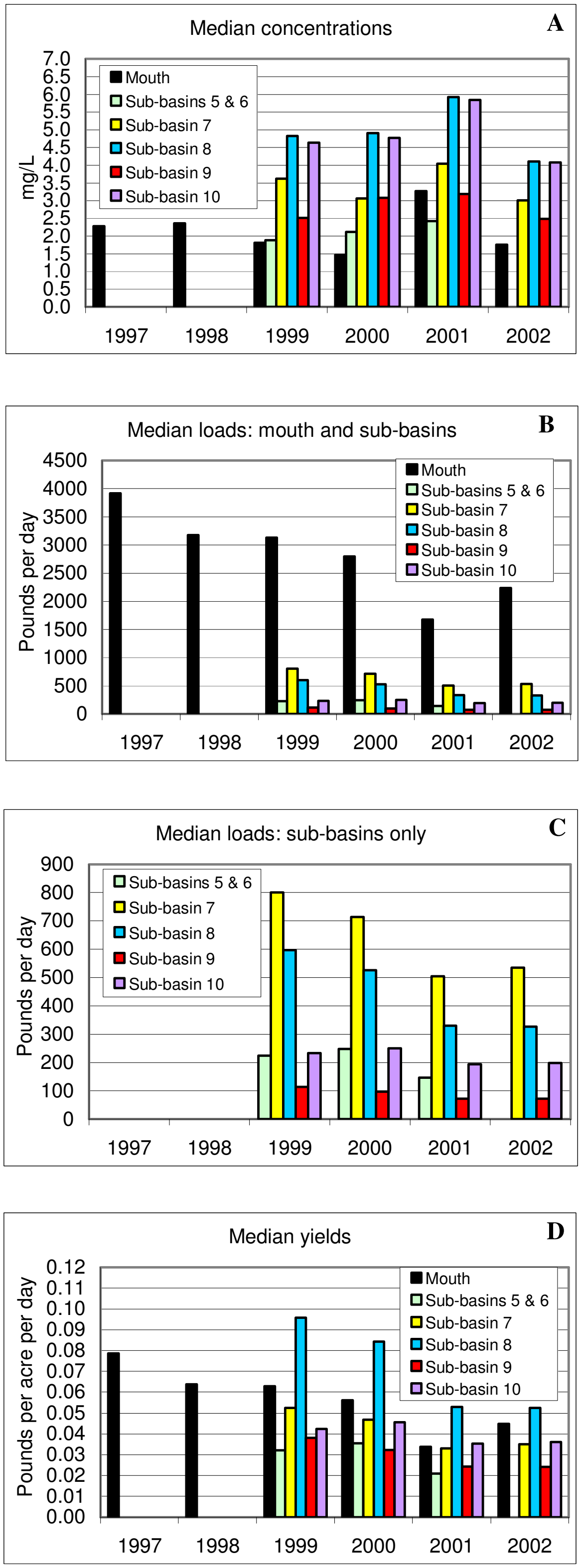
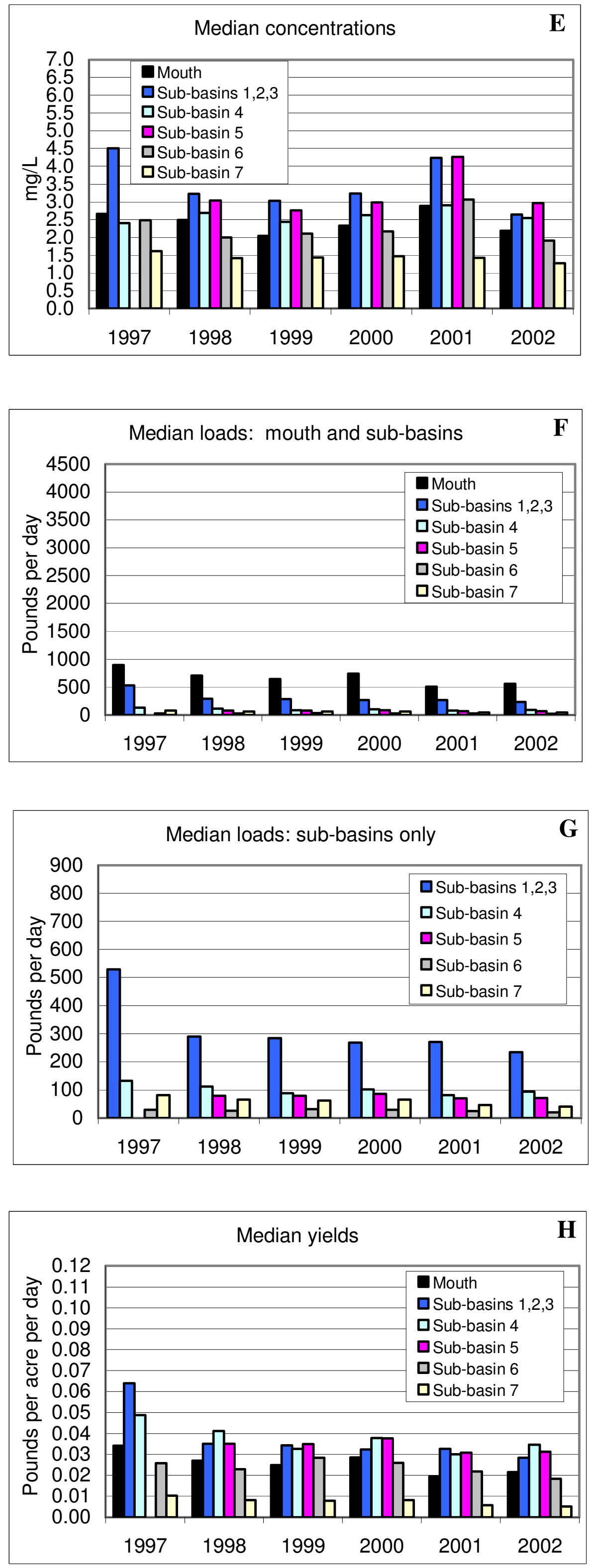


Figure 15. Nitrate+nitrite: median concentrations, loads, and yields, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.

Sulphur



Granger



groundwater in the drains. During the 2002 irrigation season, the median specific conductance in sub-basin 10 was 439 uS/cm compared to values in Granger sub-basins from 303 to 398 uS/cm. But the specific conductance of sub-basin 8 was only 343 uS/cm, so proportion of groundwater does not explain its high nitrate concentrations. The cause of elevated nitrates in sub-basin 8 is unknown.

Like discharge, the relative ranking of highest-to-lowest nitrate concentrations was fairly consistent from year to year within Sulphur sub-basins and generally the same within Granger sub-basins, suggesting that the major factors influencing variability between sub-basins were more likely permanent physical characteristics rather than variable on-farm management practices.

Loads from all sub-basins and both mouths declined, although variably. Declines in some sub-basins were substantial while in other sub-basins declines were slight.

Yields of nitrate from both watersheds declined with time. Based on the available data, we cannot determine if the declines are a reflection of changes in current fertilization practices, effect of a historical change emerging now, or another unknown factor. The yield of nitrate from sub-basin 8 of Sulphur Watershed was substantially higher in 1999 and 2000 than yields from other sub-basins for unknown reasons.

Nitrate yields were much less than typical nitrate losses from fertilizing crops. Some of the ‘missing’ nitrate may have leached to deeper groundwater sources and therefore was not collected by the drains. Some of the ‘missing’ nitrate also may have been leached to shallow groundwater, then volatilized and lost to the atmosphere as soon as the groundwater entered the irrigation return drains, or degraded by microbial processes in the substrate of the drain before surfacing. Some nitrate may be tied up in aquatic plants. Finally, some nitrate may still be in the soil and has not yet leached into shallow groundwater.

USGS currently is studying the transport of selected water quality constituents, including nitrogen, between surface water and groundwater in a secondary drain (DR2) of the Granger Watershed. These results may help us better understand the complex transport and fate of nitrogen in the area.

Total Kjeldahl nitrogen

Of all the constituents measured, we know the least about the transport and fate of total Kjeldahl nitrogen (TKN), which is organic nitrogen plus ammonia. Based on the nature of organic nitrogen (plant debris, leaves, etc.) TKN concentrations during the irrigation season should be quite variable. When irrigation water running through furrows flushes organic debris into return drains, TKN should increase. The furrow would remain relatively free of organic material for the next few irrigations, until at some point – for example during tillage or harvest – additional debris is deposited and the next irrigation carries it down the furrow. From the RSBOJC data, it is apparent that transport mechanisms affecting TKN were not the same as those affecting suspended sediment. Variability in suspended sediment concentrations explained only 14% of the variability in TKN concentrations in these watersheds (Appendix 2). Yet TKN is important to measure because organic forms of nitrogen can be transformed to nitrate.

Median concentrations, loads, and yields of TKN decreased from the mouths and the sub-basins in both watersheds. Since 2000, generally there was only a roughly 0.2 mg/L difference between the highest and lowest concentrations in the sub-basins – a fairly narrow distribution (Figure 16A&E).

TKN is also important to measure because it includes ammonia. Fresh fecal matter discharged to surface waters is typically high in ammonia. The sharp decline of the highest concentrations of TKN from 1997 to 1998 in Granger Drain (Figure 5) may have resulted, in part, from changing manure management practices at the dairies.

The yield of TKN from Sulphur Creek Wasteway was higher than from Granger Drain (except for 1997 when they were comparable), yet yields from Sulphur sub-basins were similar to Granger sub-basins. The inequity was likely due to the TKN loads from the Sunnyside urban area, unmonitored portions of the watershed, and canal water entering Sulphur Creek Wasteway (Figure 7).

Fecal coliform bacteria

Sources of fecal coliform bacteria can vary widely depending on land use.[ii] In Granger Drain, a preliminary survey during the irrigation season of 2002 using a microbial source tracking technique found the most frequently identified source of bacteria was bovine.[14] A similar study has not been conducted in Sulphur Watershed. Although fecal coliform bacteria have been reported as having the tendency to attach themselves to soil particles,[6] in these two watersheds fecal coliform concentrations did not correlate with suspended sediment concentrations (Appendix 2).

In general, conservation practices that decrease field runoff should decrease fecal coliform concentrations. Indeed, concentrations did generally decline although less so than suspended sediment (Table 1). Part of the difficulty in interpreting fecal coliform data is the high environmental variability observed. Concentrations of fecal coliform in irrigation return drains can vary by 200 to 300 percent within a few hours.[15]

[ii] In Woodland Creek, a rapidly urbanizing area near Olympia, Washington, people and dogs were the predominant sources identified (Bacteriological Contamination Source Identification, Henderson Inlet, 1999-2001, Thurston County Public Health and Social Services Department, January 2002). In the forested Lone Ranch watershed in Ferry County, deer/elk were the most frequently identified sources (Kettle Tri-Watershed Project Water Quality Summary, Ferry Conservation District, January 2002). The Woodland Creek, Lone Ranch, and Granger Drain studies relied on microbial source tracking data from Dr. Mansour Samadpour, Department of Environmental and Occupational Health Sciences, University of Washington.

Figure 16. Total Kjeldahl nitrogen (organic nitrogen+ammonia): median concentrations, loads, and yields, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.

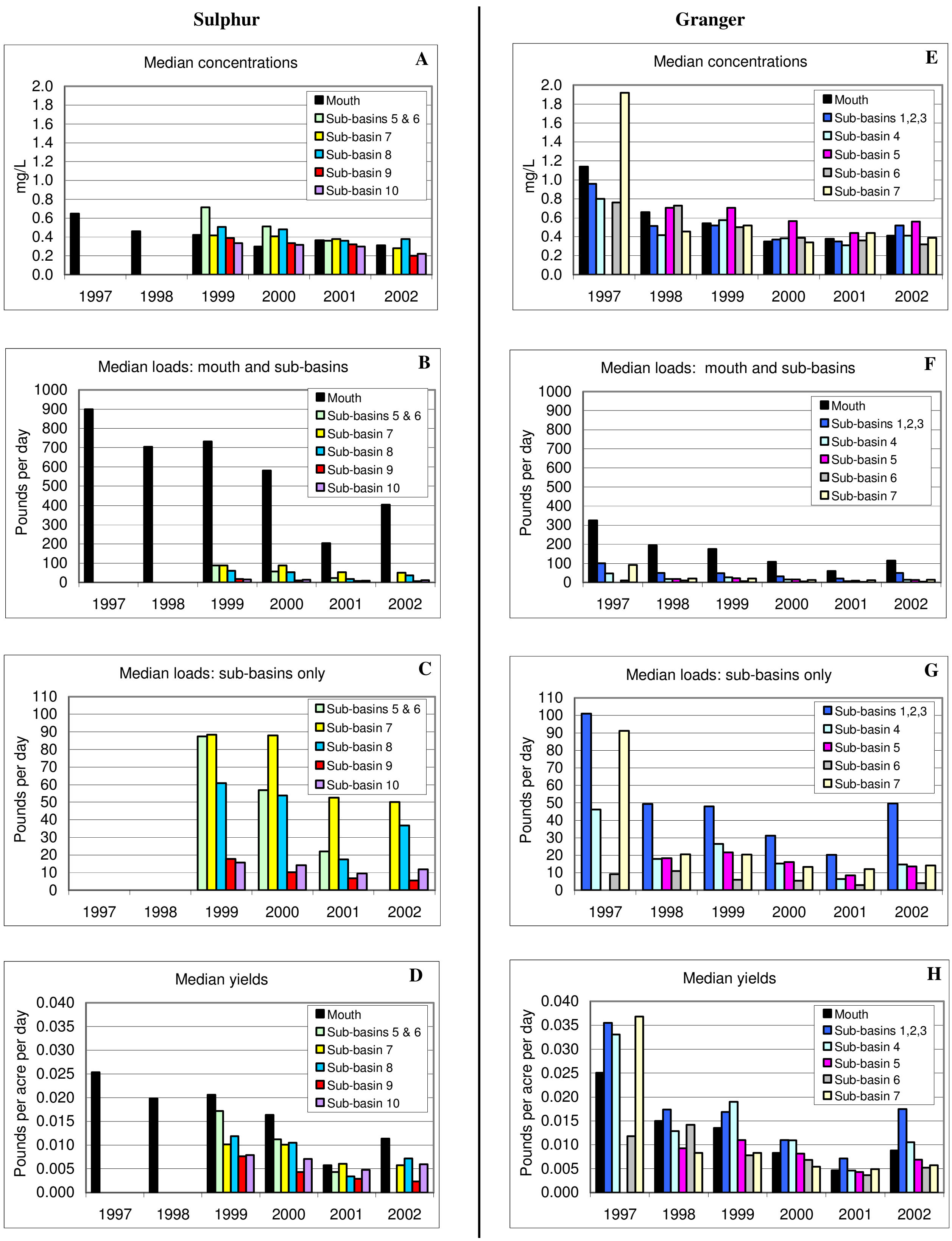
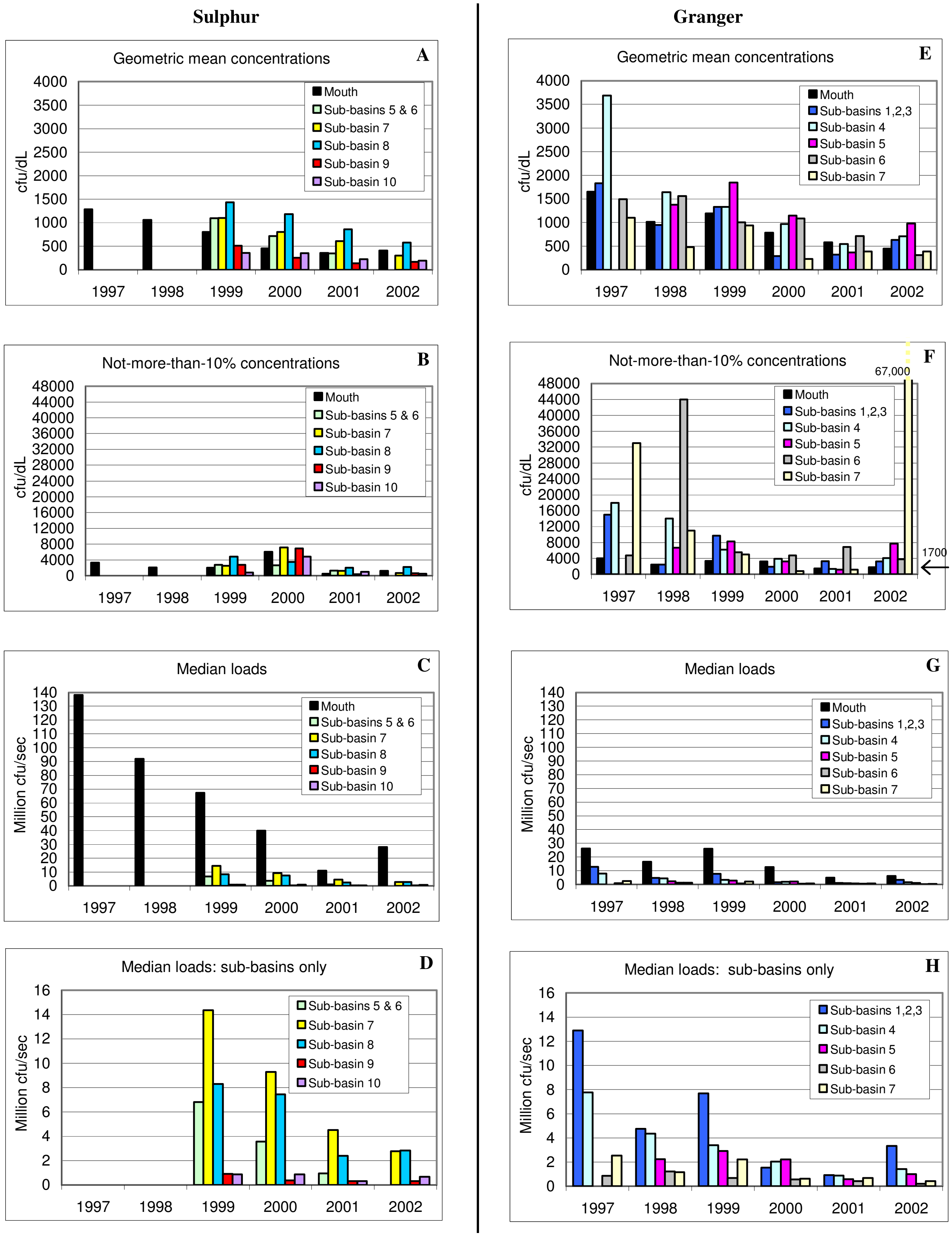


Figure 17. Fecal coliform: geometric mean and no-more-than-10%-of-all-samples concentrations, and median loads, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.



Washington State surface water quality standards set fecal coliform concentrations limits for geometric means and not-more-than-10%-of-all-samples (Table 2). Geometric means measure the central tendency of data, similar to medians, but transformed logarithmically to better address highly skewed data or anomalies.

Table 2. Washington State fecal coliform standards for surface waters (2002).

Fecal coliform limits (cfu/dL)		
	Geometric mean	Not-more-than-10%-of-all-samples
Granger Drain and Sulphur sub-drains	100	200
Sulphur Creek Wasteway	200	400
Cfu/dL= colony forming unit per deciliter. Number of colonies of bacteria in 3.4 oz. (100 milliliters or 1 deciliter) of water sample.		

For the remainder of this discussion, the value for not-more-than-10%-of-all-samples will be termed "extreme values." The extreme value is the highest value in one out of ten samples. For fewer than 20 samples, the extreme value is the same as the highest value. For 20 to 30 samples, the extreme value is the second-highest value, and so on. For RSBOJC data from 1997 to 2002, the extreme value was the highest concentration during the season, since less than 20 samples were taken at any given site for the ambient monitoring conducted.

From 1997 to 2002, despite substantial reductions in concentrations, none of the sites met the state standards.

Geometric means of fecal coliform concentrations declined in all of the Sulphur and Granger sub-basins. Extreme concentrations generally but not consistently declined. Three Sulphur sub-basins had higher extreme values in 2000 than 1999. Another notable exception was Granger sub-basin 7, which had a higher concentration (67,000 cfu/dL) in 2002 than any other sample from the data analyzed for this report. The extreme one-day fecal coliform concentration in sub-basin 7 was accompanied by unusually high concentrations of ammonia, organic nitrogen, and phosphorus, but not unusually high turbidity. This combination of results is a pattern typically associated with a direct discharge of manure. The importance of this single sample is illustrated by the arrow in Figure 17F, which shows what the season's extreme result would have been (1700 cfu/dL) without that single sample.

A "load" of fecal coliform is somewhat of an abstract concept because fecal coliform do not have measurable mass. This report uses a load surrogate of colonies per second (as used by USGS).[15] Loads from the mouth and sub-basins in Sulphur substantially declined (Figure 17C&D). Loads from the mouth of Granger Drain were more variable but declined from 1999 to 2002 (Figure 17G). Loads from the Granger sub-basins also declined, in some cases substantially (Figure 17H). As with the other constituents, the load from Sulphur was higher than that from Granger.

A "yield" of fecal coliform is an even more abstract concept and was calculated only to allow comparisons between drainage areas on a per-acre basis. The yield of fecal coliform was higher from Sulphur Creek Wasteway than from Granger Drain in four out of six years, although the magnitude of the differences varied considerably from year to year (Figure 18). The yields from both watersheds decreased with time.

Total dissolved solids
Total dissolved solids (TDS) is a conservative parameter, indicating how other constituents would be transported without deposition, re-suspension, or transformation processes occurring. For this report, TDS was not measured analytically but was estimated by multiplying specific conductance values of the drain water by 0.67.[16] The TDS results (Figure 19) were similar to nitrate results (Figure 15A&E) in some sub-basins but not in others. It is unclear from these data whether nitrate is not behaving conservatively or not.

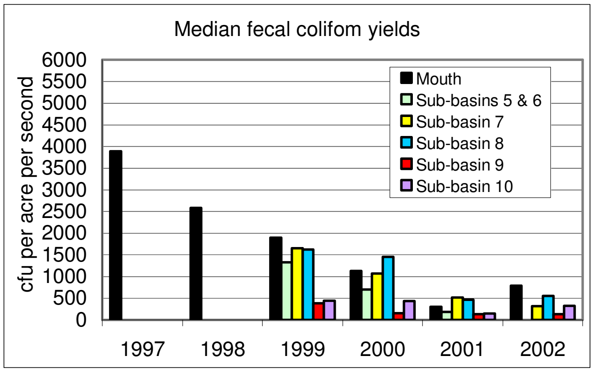
Why the irrigation season improvements?
Four elements from the above discussion suggest that the water quality improvements were due to conservation practices, not random chance or changes in water availability.

(1) Improvements were not localized nor limited to one or two years.
(2) The simultaneous reduction in loads and concentrations. To reduce loads and concentrations simultaneously, one of two changes must occur: (a) either the drain becomes less efficient at transporting the constituent (e.g., particles settle out due to decreased velocities or are filtered out by aquatic plants); or (b) the drain receives less of the substance. Changed transport efficiency is an unlikely explanation. Canal diversions remained stable except for the 2001 drought. Drain maintenance practices, which can change transport efficiencies due to dredging, are intermittent and variable. Effects from aquatic plant and algae growth also likely would be variable. Yet yields reduced in every sub-basin from 1999 to 2002 for all constituents except nitrate.
(3) The combination of decreasing extreme concentrations of fecal coliform, total Kjeldahl nitrogen, and total phosphorus throughout Sulphur and Granger watersheds suggests a decreasing frequency of discharges of high-volume manure to the drains, most likely as a result of BMPs related to manure management.
(4) Higher values (90th and 75th percentiles) of most constituents decreased more than the medians. High values are most strongly influenced by infrequent, intermittent concentrated discharges, such as turbid on-farm runoff from a field – the focus of most BMP efforts during these years.

Additionally, as discussed in the following section, the difference in concentrations between the irrigation season and non-irrigation season narrowed substantially.

Figure 18. Fecal coliform: median yields, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons

Sulphur



Granger

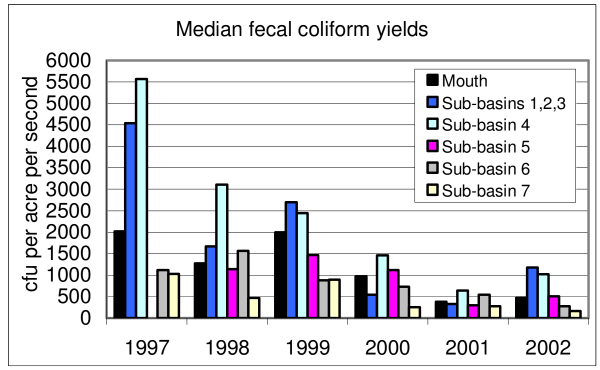
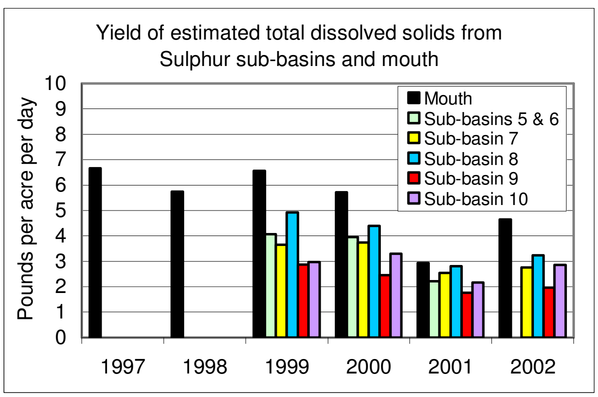
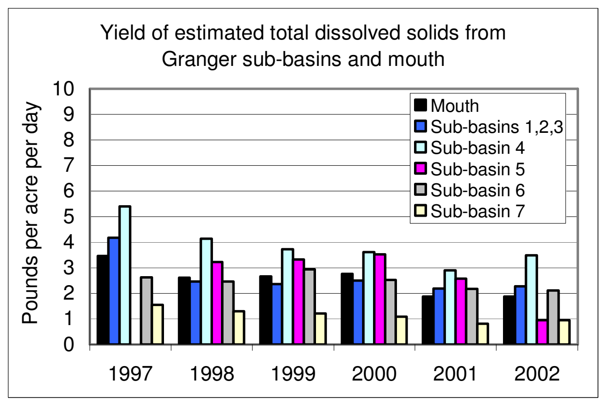


Figure 19. Total dissolved solids (estimated): median yields, Sulphur and Granger watersheds, 1997 to 2002 irrigation seasons.

Sulphur



Granger



Non-irrigation season

During the non-irrigation season, RSBOJC sampled only monthly, instead of twice monthly as during the irrigation season. Median values during the non-irrigation season are more likely to be variable because of the smaller number of samples.

Discharge
Median instantaneous discharge during the non-irrigation seasons was relatively stable in both drains (Figure 20A&D). Discharge from Sulphur Creek Wasteway during the non-irrigation season was roughly one-sixth to one-quarter of discharge during the irrigation season. Discharge from Granger Drain during the non-irrigation season was approximately one-third to one-half of discharge during the irrigation season. One reason for the difference between watersheds is the canal spill water added to Sulphur Creek Wasteway during the irrigation season.

Suspended sediment
In 1997, irrigation season concentrations in both drains were much higher than non-irrigation season concentrations (Figure 21B&E). The significant declines during subsequent years in irrigation season concentrations resulted in a narrowing gap between irrigation and non-irrigation seasons. In 2002, the non-irrigation season was actually higher than the irrigation season in Sulphur Creek Wasteway. Considering that yearly precipitation, 75 percent[11] of which typically occurs during the non-irrigation season, is only seven inches but irrigated land may receive three acre-feet of water per acre[iii], such a rapidly-narrowing gap between non-irrigation season and irrigation season concentrations strongly suggests substantial improvements in on-farm irrigation water management.

Non-irrigation season loads were comparable between watersheds (Figure 20C&F).

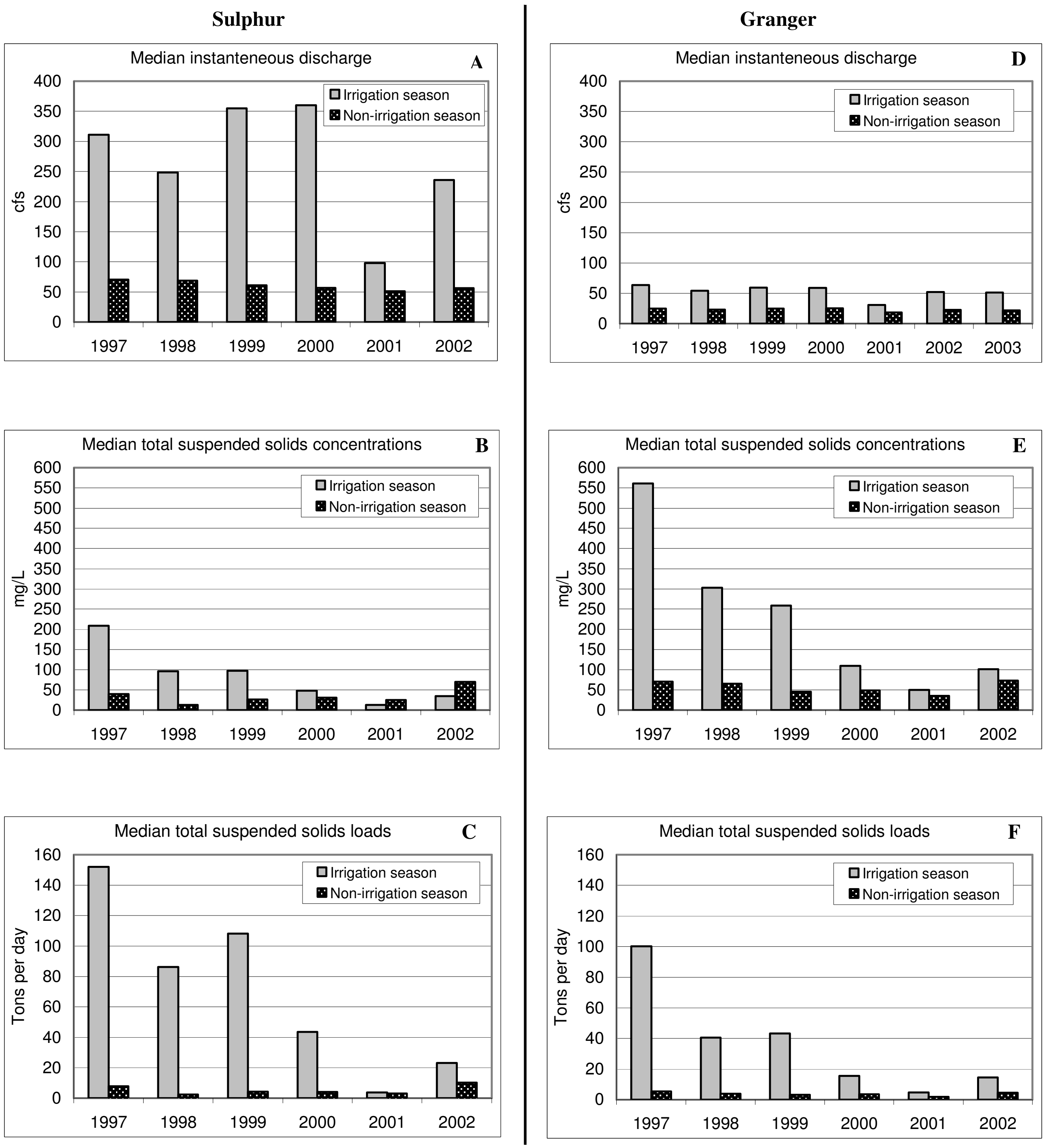
Total phosphorus
Non-irrigation season total phosphorus concentrations in Sulphur Creek Wasteway were comparable from 1997 to 2002 (Figure 21A). In Granger Drain, concentrations declined sharply from 1997 to 1998 then became comparable from 1998 to 2002 (Figure 21B).

In Sulphur Creek Wasteway from 1997 to 1999 and in Granger Drain from 2000 to 2002, total phosphorus concentrations in the non-irrigation season were quite similar to the irrigation season – another indication that phosphorus does not follow the same fate as suspended sediment. From 2000 to 2002, phosphorus concentrations were higher in Sulphur Creek Wasteway during the non-irrigation season than the irrigation season.

Two possible reasons for non-irrigation season concentrations being higher than the irrigation season are: (1) non-irrigation season phosphorus concentrations reflect conditions in nearby shallow groundwater; and/or (2) desorption of phosphorus from sediment in the bottom of the drains.

[iii] Irrigation rates vary widely between crops. A rate of three acre-feet is commonly used locally for planning purposes but is based on water rights not actual water use.

Figure 20. Irrigation season and non-irrigation season median instantaneous discharges, and median concentrations and loads of suspended sediment, Sulphur Creek Wasteway and Granger Drain, 1997 to 2002.



As the phosphorus loads during the irrigation season declined and the non-irrigation season loads remained comparatively stable, the difference between irrigation and non-irrigation season loads decreased (Figure 21B&F).

Nitrate

During the non-irrigation seasons there was a slight decrease over the years in nitrate concentrations in Sulphur Creek Wasteway. In Granger Drain, non-irrigation season concentrations were equivalent in 1997 and 2002 with slightly lower concentrations in the intervening years. Non-irrigation season concentrations in Granger Drain were roughly one mg/L less than in Sulphur Creek Wasteway except for 2002 when they were similar (Figure 21C&G).

The concentration of nitrate during the non-irrigation season (Figure 21C&G) was much greater than the irrigation season in both drains. During the non-irrigation season, the water in the drains becomes nearly entirely groundwater, which has elevated concentrations of nitrate. During the irrigation season, the irrigation-induced runoff dilutes the higher concentrations in groundwater.

The loads from Sulphur and Granger watersheds were similar between irrigation and non-irrigation seasons (Figure 21D&H). As the concentration of nitrate increased during the non-irrigation season, the amount of water discharged from the drains decreased, resulting in similar amounts of pounds per day of nitrate discharged to the Yakima River year-round. Another way of looking at the similar loads between seasons is that irrigation-induced runoff flowing to the drains during the irrigation season does not add substantially to the load of nitrates.

Total Kjeldahl nitrogen

Non-irrigation season concentrations in Granger Drain decreased markedly from 1997 to 1998 then were relatively stable from 1998 to 2002. Non-irrigation season concentrations in Sulphur Creek Wasteway also decreased from 1997 to 1998 then gradually increased from 1998 to 2002 for unknown reasons. Concentrations in Sulphur Creek Wasteway were higher than concentrations in Granger Drain except for 1997 when they were comparable (Figure 22A&E).

In Sulphur Creek Wasteway, total Kjeldahl nitrogen concentrations were higher during the non-irrigation season than the irrigation season for all six years. In Granger Drain, the irrigation season concentrations were higher than the non-irrigation season except for 2000 and 2002 when they were equivalent.

In both drains, irrigation season loads were higher than the non-irrigation season except for 2001 in Sulphur Creek Wasteway when they were equivalent (Figure 22B&F).

Fecal coliform

Median non-irrigation season concentrations were variable in both drains (Figure 22C&G). Non-irrigation season concentrations were greater in Sulphur Creek Wasteway than Granger Drain, except for 1997. Fecal coliform concentrations were generally

Figure 21. Irrigation season and non-irrigation season median concentrations and loads of total phosphorus and nirate+nitrite, Sulphur Creek Wasteway and Granger Drain, 1997 to 2002.

Sulphur | **Granger**

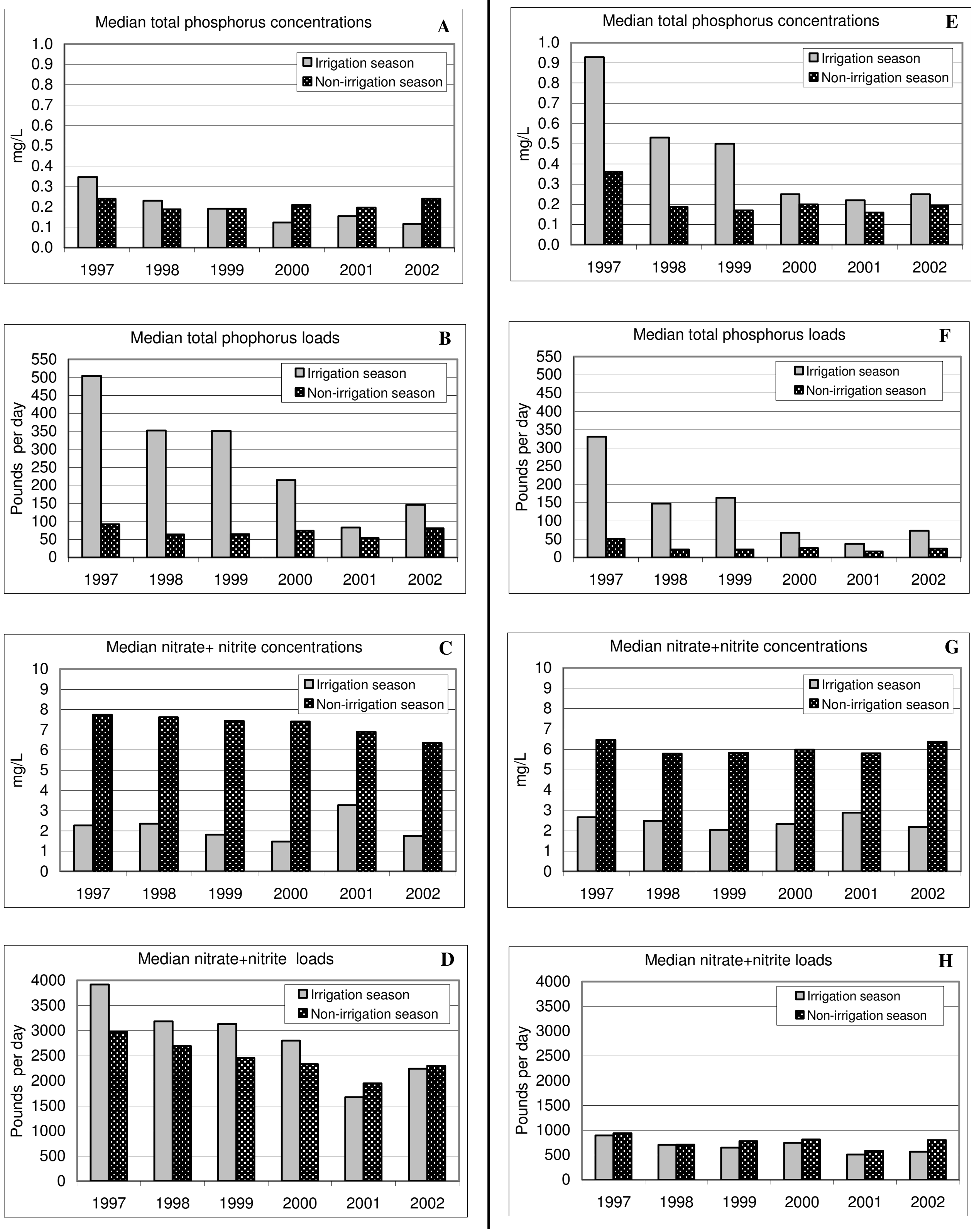
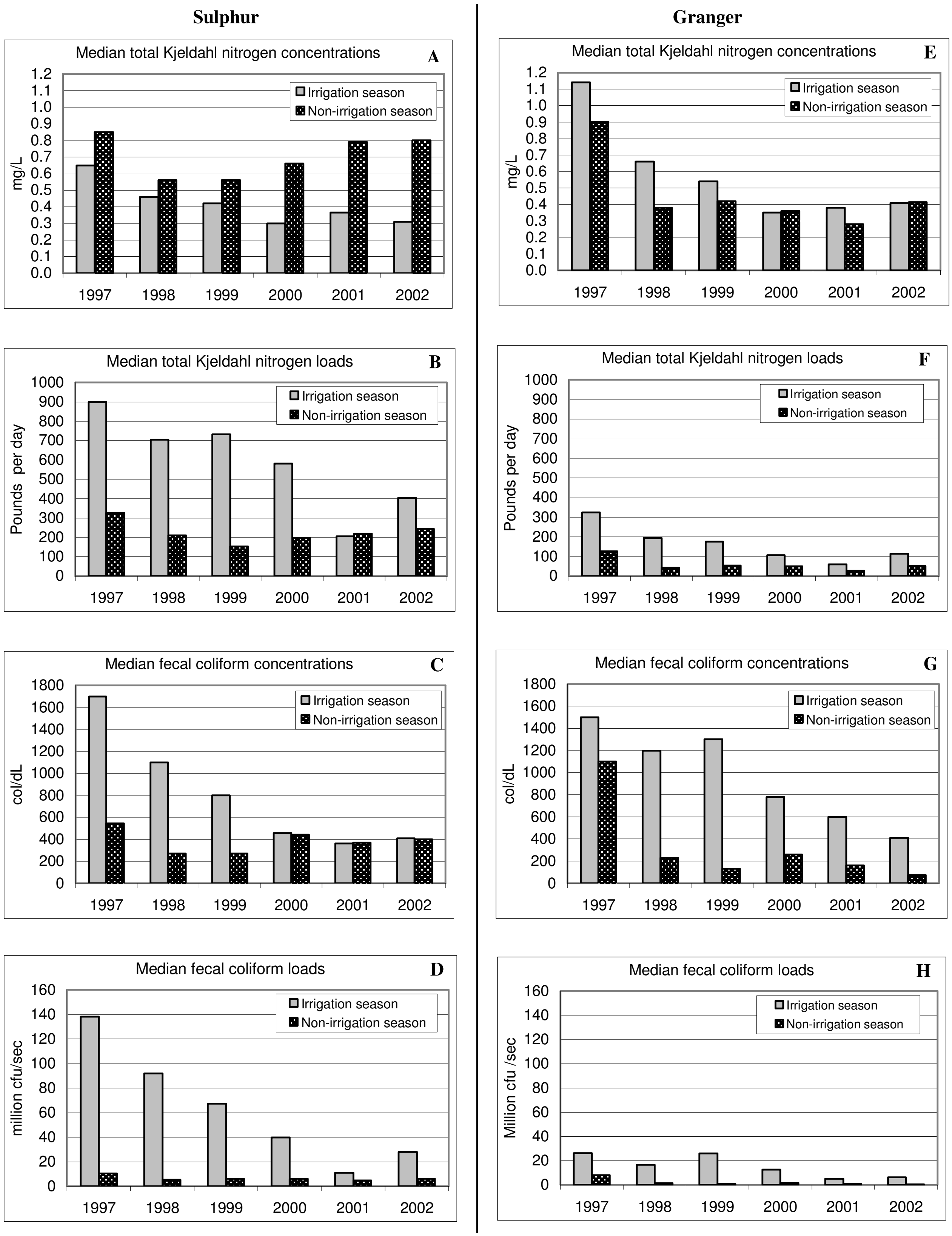


Figure 22. Irrigation season and non-irrigation season median concentrations and loads of total Kjeldahl nitrogen and fecal coliform, Sulphur Creek Wasteway and Granger Drain, 1997 to 2002.



greater during the irrigation season in both drains but were similar to the non-irrigation season in Sulphur from 2000 to 2002. Irrigation season loads of fecal coliform were always greater than non-irrigation season loads (Figure 22D&H).

For any constituent transported primarily through runoff (e.g., suspended sediment, fecal coliform), concentrations during the non-irrigation season that are approaching or even exceed irrigation season concentrations are of concern for future BMP implementation efforts, since the current focus is largely on irrigation season practices.

Quality assurance

The quality of the water chemistry and discharge data was excellent (Table 3). When discussing the monitoring results in the above sections, differences between two results (for example, the 1997 versus 1999 median phosphorus concentrations) were not considered as a 'real' difference unless the difference was greater than the variability between replicates.

Table 3. Median relative percent differences between replicates, 1997 to 2002.

Parameter	**Relative percent difference**	
	RSBOJC Lab [iv]	*Field* [iv]
Turbidity	0.9	1.4
Total suspended sediment	0.9	2.5
Fecal coliform	10.6	15.0
Specific conductance	N/A	0.1
Discharge	N/A	1.3
	Bureau of Reclamation Lab	*Field*
Total phosphorus	3.1	3.2
Nitrate/nitrite	0.6	0.6
Total Kjeldahl nitrogen	4.8	4.9

The GIS layer of soil types within the watersheds was based on an NRCS layer of soil types for Yakima County with an estimated accuracy of +/-20 feet. The GIS layer of slopes was created by the Kittitas County Conservation District from a 10-meter digital elevation model (DEM) from USGS. Accuracy was estimated to be within +/- 5 meters.[v]

GIS layers of drainage area boundaries were created by SYCD using a combination of existing boundary delineations from other agencies (sometimes with different delineation

[iv] Lab replicates are two analyses conducted on the same sample. Field replicates are analyses on two samples taken in the field, generally at the same location and close in time.
[v] The exact language provided by the Kittitas County Conservation District was "Vertical positional accuracy is based upon the use of USGS-source quadrangles which are compiled to meet National Map Accuracy Standards (NMAS). NMAS vertical accuracy requires that at least 90 percent of well defined points tested be within one half contour interval of the correct value." (Dec.17, 2004 e-mail from Suzanne Wade, GIS specialist, Kittitas County Conservation District).

goals, such as 'irrigated acres served by the Sunnyside Canal') and color aerial photographs taken in the summer of 2002. Uncertainty of the boundary delineations was estimated by comparing the boundaries to the other agencies' efforts, with relative percent differences ranging from 2 to 30 percent.

GIS layers showing crop and irrigation types were intended to be visual planning aids and are not accurate to the field level. Many fields had multiple crops or irrigation types. Because the crop and irrigation data were merged with a parcel layer, fields smaller than entire parcels had to be combined into a single crop or irrigation type. However, the data analyses in this report were performed on the field-level crop and irrigation data as provided by the irrigation districts.

The quality of the data on crop and irrigation type was variable. To estimate the degree of uncertainty in the crop and irrigation data, the irrigation district survey results were compared against two other agency surveys of crop and irrigation types within Granger: (1) WSU conducted a field-by-field survey of Granger crop and irrigation types in 1999 of land below the Sunnyside canal; and (2) USGS surveyed the entire irrigated portion of the watershed in 2003.

The results of the surveys were variable even when considering only the crops with the highest percentages (Table 4). Because of the uncertainty in the crop and irrigation data, no attempt was made to analyze the data on a sub-basin level.

Table 4. Percent acres of major crops from various surveys.

	Surveys below the Sunnyside Canal		*Surveys of all irrigated areas*	
Crop type	**Irrigation Districts, 2000**	**WSU, 1999**	**Irrigation Districts, 2000**	**USGS, 2003**[17]
Corn	25%	25%	25%	26%
Pasture	23%	17%	19%	8%
Asparagus	12%	12%	4%	3%
Grapes	12%	9%	11%	10%
Hay	14%	10%	5%	13%
Orchard	9%	3%	27%	32%

Why the differences in water quality between Sulphur and Granger watersheds?

As already mentioned, one reason that Sulphur Creek Wasteway had lower concentrations of suspended sediment, phosphorus, total Kjeldahl nitrogen, and bacteria than Granger Drain was the relatively clean canal water spilled to the wasteway which diluted the return flows. But the highest concentrations (90^{th} and 75^{th} percentile values) of most constituents also were lower in Sulphur sub-drains than Granger sub-drains (Figure 6), none of which receive significant volumes of spill water. So the spill water cannot be the only reason for the differences in water quality.

Could the differences in water quality be due to differences in land use or physical characteristics of the watersheds? Which characteristics most strongly influence water quality? For suspended sediment and other surface-transported constituents, the same factors affecting the quality and quantity of on-farm runoff affect water quality in the irrigation return drains. These factors include: type of irrigation system, slope, soil type, crop type, and furrow length in rill-irrigated fields. Each of these characteristics was evaluated, using parcel size as a rough indicator of furrow length. Finally, the number of acres to which BMPs were known to have been applied during these years was considered.

Crop and irrigation types

Data on crop and irrigation types were gathered in 2000 by Sunnyside Division and Roza Irrigation District staff. Data were gathered parcel-by-parcel. For parcels having more than one crop or irrigation type, growers or staff estimated proportions of each crop or irrigation type.

There were two differences in crop types that were large enough to be of interest – relatively more corn in Granger Watershed and more grapes in Sulphur Watershed (Figure 23), which may help explain the higher turbidity and suspended sediment concentrations in Granger. Soil generally erodes more from cornfields than orchards or vineyards, all other factors being equal.

The proportions of drip, sprinkler, and rill irrigation systems were essentially the same in both watersheds (Figure 23) even though the distribution of irrigation and crop types was not uniform within each watershed (Figures 24 and 25). For example, rill irrigation of row crops was dominant closest to the valley floor while sprinkler-irrigated orchards and vineyards were more frequently located higher on the hillsides.

Based on a Department of Ecology 1999 statewide survey, 29% of the irrigated acres in Granger and 12% of the irrigated acres in Sulphur were owned by dairies. This may help explain the higher concentrations of fecal coliform and phosphorus in Granger Drain. Manure is applied as a fertilizer to diverse crops but generally close to the source of manure due to transportation costs.

Slope and soil type

The irrigated portion of Granger Watershed had a higher proportion of silt loam soils (89.9%) than Sulphur Watershed (56.9%) (Figure 23). Sulphur Watershed had significant proportions of fine sandy loams, loamy fine sands, and very fine sandy loams – all of which are more erodable soils than silt loams.[18] Interestingly, Sulphur drains were generally less turbid than Granger drains.

While a soil's tendency to erode is important in evaluating potential effects on surface waters, so is the relative proportion of very fine clay particles in the soil. Very fine clay particles will stay suspended in water longer than sand-sized particles. Silt loam soils have a higher proportion of clay particles than the sandy soils listed above. Thus, while a higher proportion of the soils in Sulphur are more likely to erode than those in Granger (all else being equal) the soil particles in Sulphur drains are also more likely to settle in water quickly and be transported shorter distances from their source.

The differences in slopes between the watersheds also may help explain lower suspended sediment concentrations and turbidity in Sulphur than Granger sub-basins. The irrigated portions of Sulphur Watershed had a higher proportion of flat ground (less than 1% slope) and a lower proportion of relatively steep ground (over 8% slope) than Granger Watershed (Figure 23).

Parcel size (furrow length)

Because longer furrows have the potential to cause more erosion than shorter furrows (all else being equal), larger parcels, which lend themselves to longer furrows, might produce more irrigation-induced soil erosion than smaller parcels. On the other hand, it is less cost-effective to convert smaller parcels from rill to sprinkler or drip irrigation. The proportions of different ranges in parcel size were estimated for each watershed but the differences were minor (Table 5).

Table 5. Proportion of different parcel sizes as a percent of total irrigated acreage within Sulphur and Granger watersheds.

	Sulphur	**Granger**
Parcel size (acres)	**Percent of irrigated acres**	
0-2	5	2
2-10	14	9
10-20	14	14
>20	66	74

BMP rates

Implementation rates of government-funded BMPs were essentially the same in Sulphur and Granger watersheds, varying between 9 to 12 percent (see next section), thus not contributing to an explanation of the differences in water quality between Sulphur and Granger watersheds.

Figure 23. Crop types, irrigation types, soil types, and slopes within Sulphur and Granger watersheds.

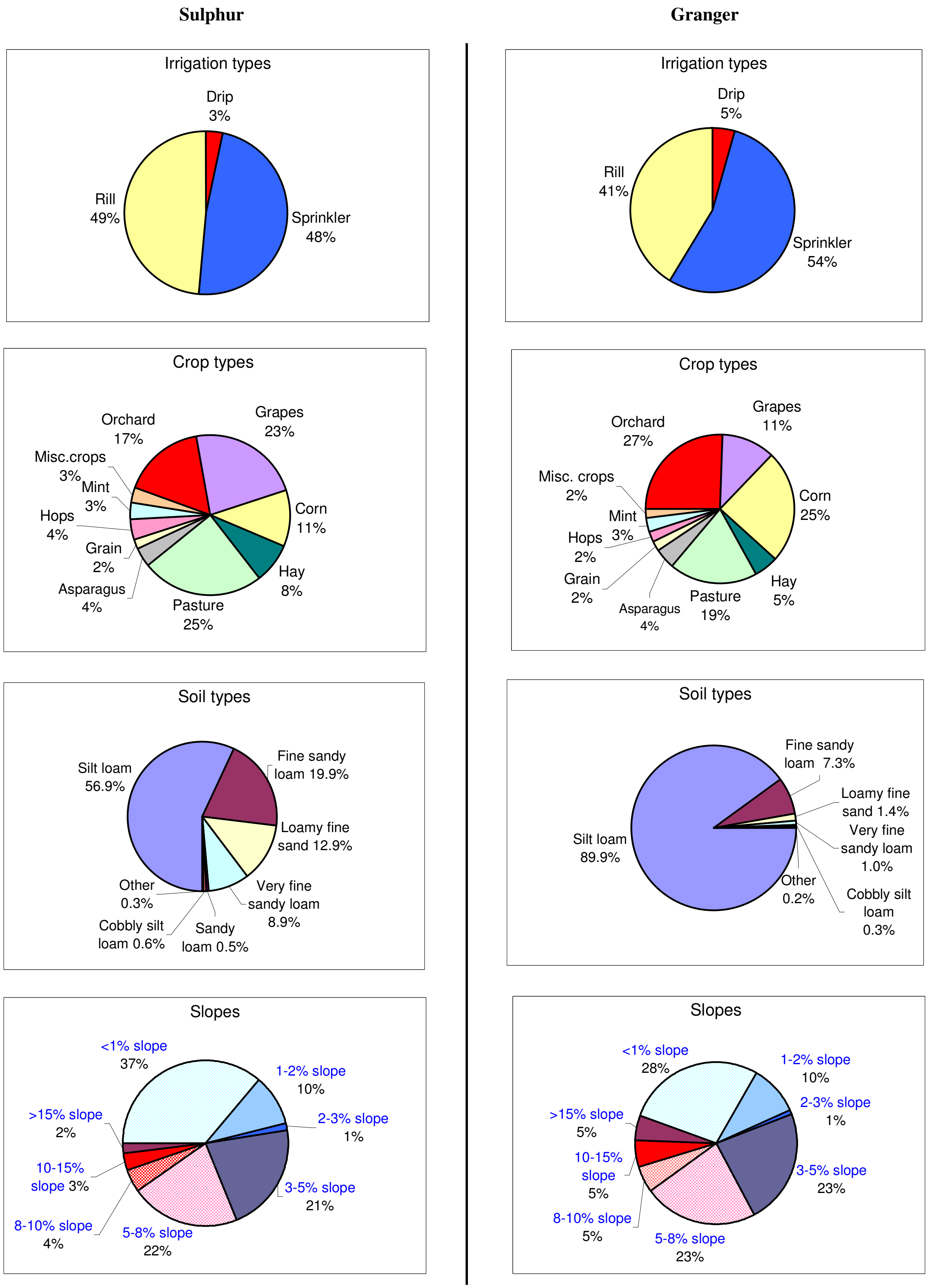
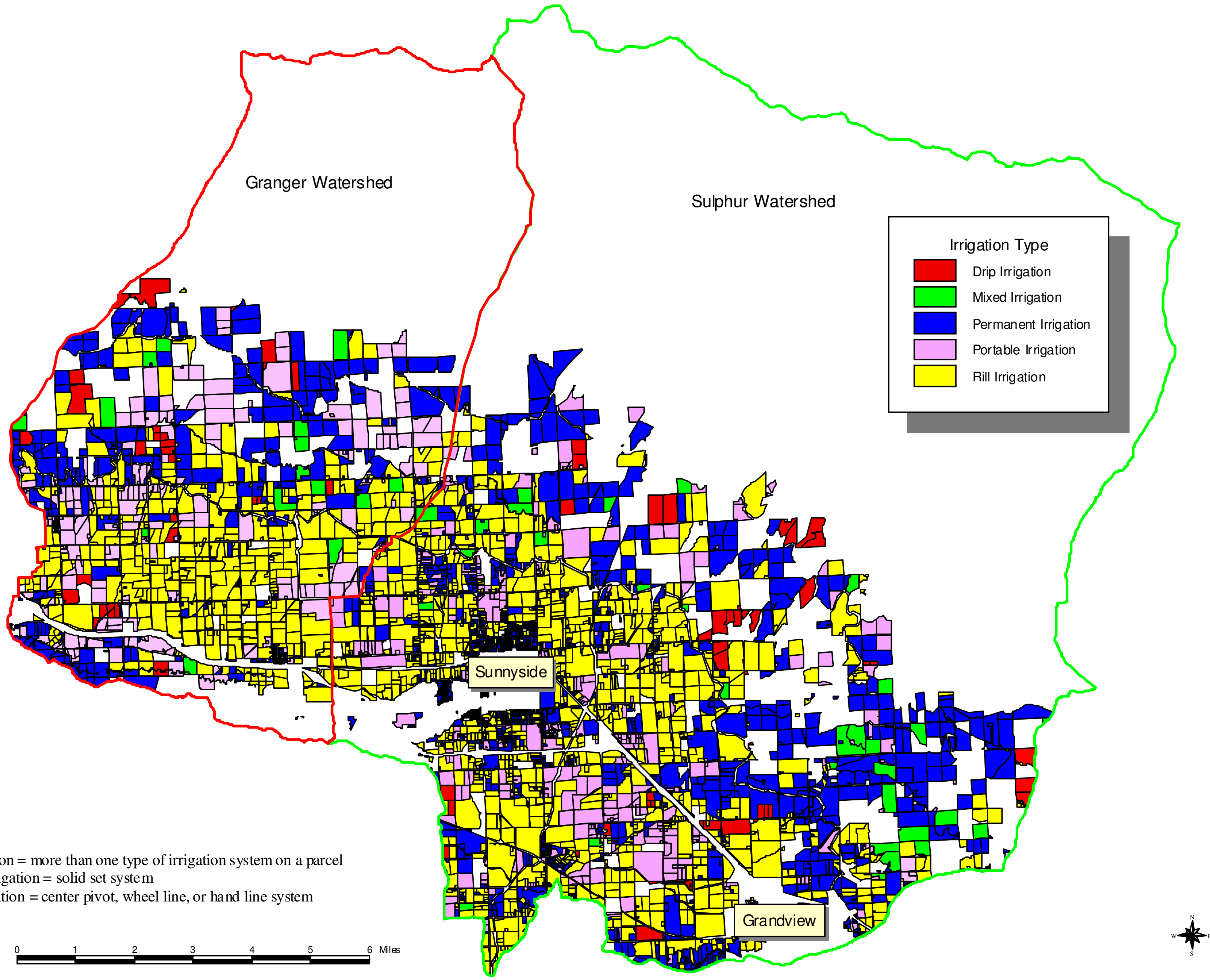
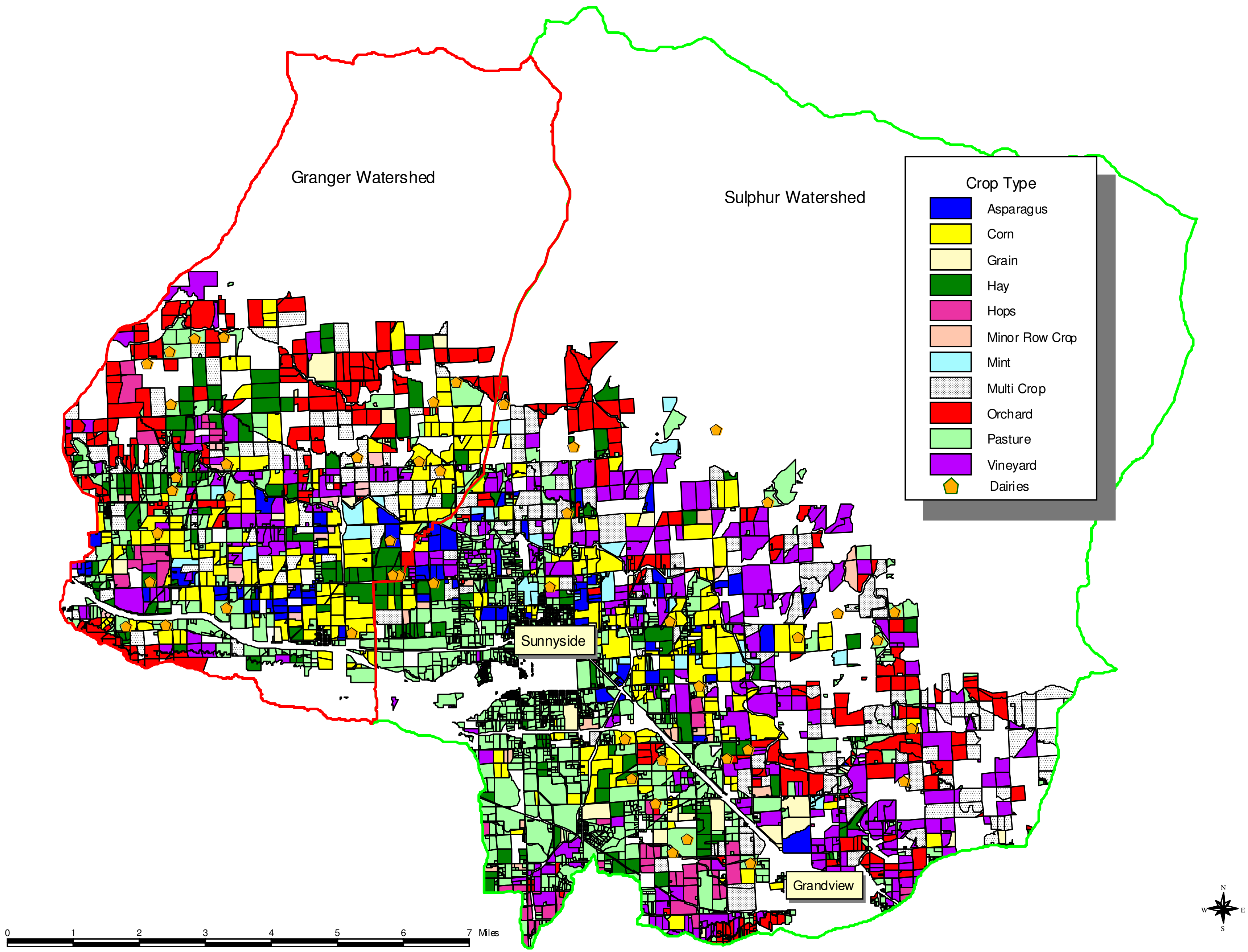


Figure 24. Distribution of irrigation types within Sulphur and Granger watersheds, summer 2000.



Notes:
Mixed irrigation = more than one type of irrigation system on a parcel
Permanent irrigation = solid set system
Portable irrigation = center pivot, wheel line, or hand line system

Figure 25. Distribution of irrigated crop types within Sulphur and Granger watersheds, summer 2000.



Relating BMP implementation rates to water quality improvements

While BMP rates did not help explain the differences between water quality in Sulphur and Granger watersheds, perhaps conservation practices, as reflected by BMP implementation rates, could help explain water quality improvements over time in these watersheds. To measure rates of changing conservation practices, data were gathered on government-funded BMP implementation projects and entered into a GIS layer (Figure 26). The GIS layer is parcel-based. It is not accurate to the field-level, as some parcels only had BMPs installed on a part of the parcel. However, the acreage used to calculate percent of watershed improved was based on the actual acreage of each project, not the more generalized parcel layer.

The funding sources reviewed were: (1) Natural Resources Conservation Service's Environmental Quality Incentives Program; (2) Washington State Conservation Commission's dairy cost-share program and implementation funding that SYCD chooses to use for cost-share; and (3) Roza-Sunnyside Board of Joint Control's $10 million loan program.

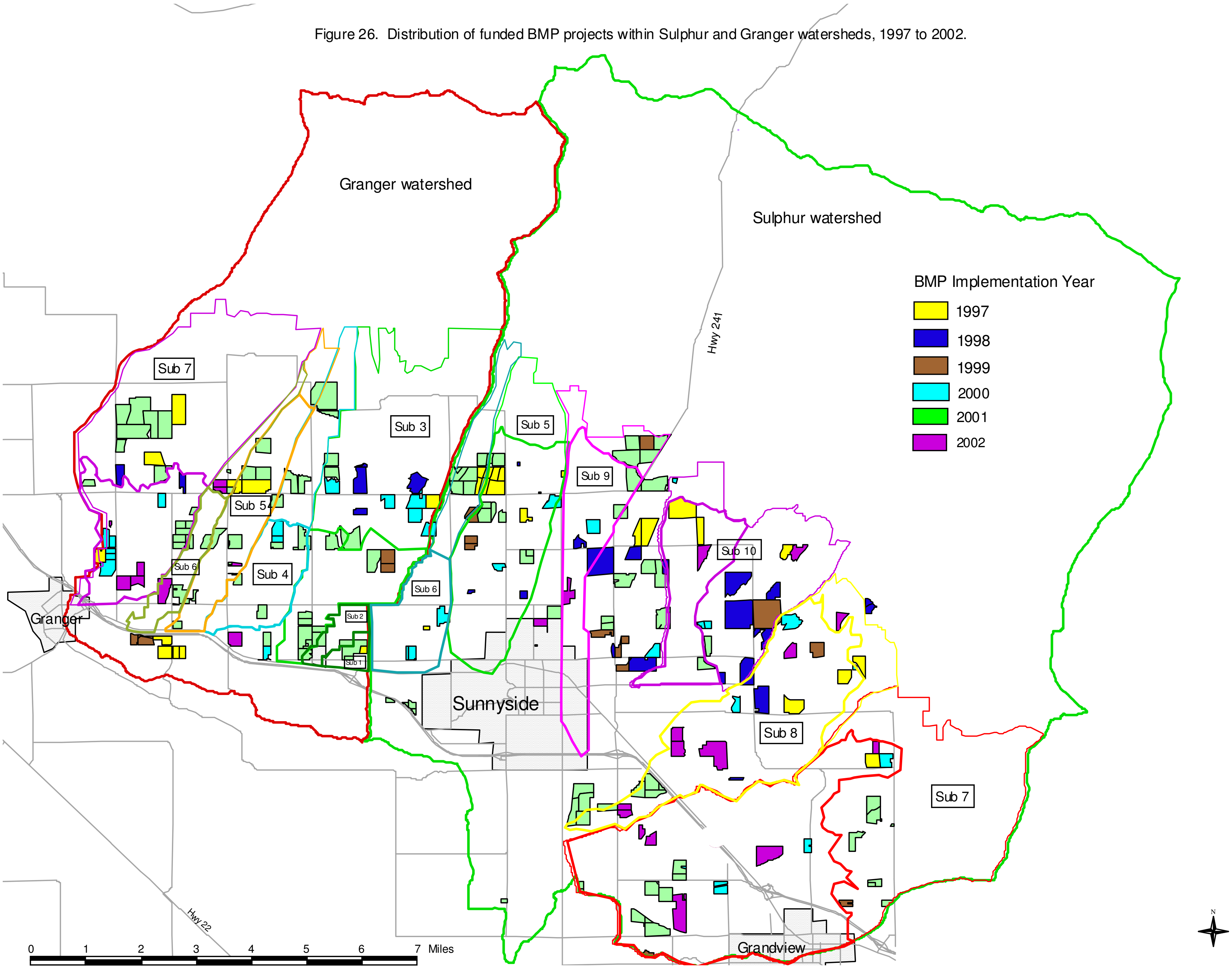
As a percent of the irrigated acres within each watershed, there was little difference between watersheds in BMP implementation rates (Table 6). But there was a wider range in implementation rates among sub-basins. There was also a wide range in percent decreases of total suspended solids (TSS) concentrations among sub-basins.

Table 6. Acres of funded BMP projects implemented by private landowners, 1997 to 2002.

	Funded BMP acres within runoff areas	**Percent of runoff acres with BMPs applied**	**Percent decrease TSS concentration 1997/1999 to 2002**
Sulphur Watershed (totals)	*3239*	*9.1*	*83*
Sub-basins 5 & 6	709	13.9	91
Sub-basin 7	549	6.3	78
Sub-basin 8	676	13.2	75
Sub-basin 9	157	6.7	80
Sub-basin 10	142	7.1	10
Granger Watershed (totals)	*1587*	*12.2*	*82*
Sub-basins 1,2,3	377	13.3	36
Sub-basin 4	137	9.8	80
Sub-basin 5	355	18.0	68
Sub-basin 6	92	11.7	94
Sub-basin 7	438	17.7	83

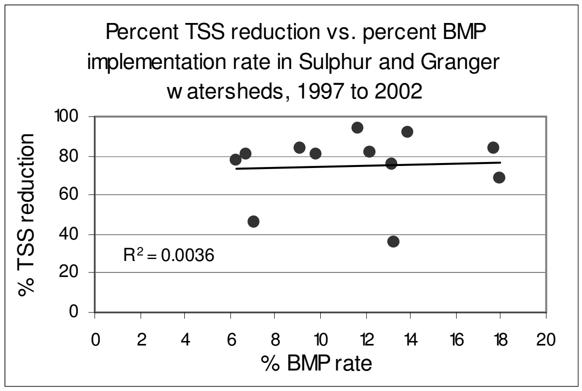
The percent improvement in suspended sediment concentrations from 1997 to 2002 (or 1999 to 2002 for Sulphur sub-basins) was compared against the percent of each sub-basin

Figure 26. Distribution of funded BMP projects within Sulphur and Granger watersheds, 1997 to 2002.



to which BMPs were applied during the same years (Figure 27). Percentages for the entire watersheds were also included. Sub-basins with the highest BMP implementation rate would be expected to be those with the highest water quality improvement. This was not the case. For example, approximately 80% reductions in suspended sediment concentrations were seen in a sub-basin with an 18% BMP implementation rate but also in a sub-basin with only a 6% BMP implementation rate.

Figure 27. Funded BMP rates compared to water quality improvement rates.



BMP implementation rates were also evaluated by year for each watershed (Table 7). BMP rates within the entire irrigated portion of the watershed were calculated ("irrigated acres"), as well BMP rates only within the portions of the watersheds that drain into the return drains ("runoff acres"). The yearly BMP implementation rates did not follow the same pattern of water quality improvement rates for either Granger or Sulphur watersheds. For example, water quality improved substantially from 1997 to 1998, yet relatively few acres of funded BMPs were installed during 1997. From 1999 to 2000, water quality also substantially improved for many constituents, yet relatively few acres were improved in 1999 by the funded BMPs.

Table 7. Funded BMP acres by year.

	Sulphur Watershed		**Granger Watershed**	
BMP implementation year	Irrigated acres with funded BMPs, per year	Runoff acres with funded BMPs, per year	Irrigated acres with funded BMPs, per year	Runoff acres with funded BMPs, per year
1997	515	401	386	301
1998	781	418	434	22
1999	360	188	152	152
2000	416	353	450	238
2001	1794	1278	1601	1048
2002	450	405	200	166

The cost-share and loan data were also analyzed by type of funding source and by farm type to give a perspective on the uses of the funding programs. The Environmental Quality Incentives Program funded the most acres in these watersheds during these years. Many growers were able to combine funding sources, as indicated in Table 8 by multiple agency listings. For example, “EQIP/RSBOJC” means that both EQIP cost-share funds and a low-interest loan from RSBOJC were used for the project.

Funding from the Washington State Conservation Commission (WCC) consisted primarily of cost-share for dairies specifically appropriated by the state legislature for dairy BMPs. The higher proportion of dairy BMP acres in Granger reflects its higher proportion of dairy acreage.

Table 8. Funded BMP acres by funding source and farm type.

	Sulphur	**Granger**
Funding source		
Environmental Quality Incentives Program (EQIP)	1559	1299
Washington Conservation Commission (WCC)	861	682
Roza-Sunnyside Board of Joint Control (RSBOJC)	502	462
WCC/RSBOJC	366	401
EQIP/RSBOJC	577	345
WCC/EQIP	450	33
sum	*4315*	*3222*
Farm type		
Farm	3426	1752
Dairy	889	1470
sum	*4315*	*3222*

The lack of direct relationship between the government-funded BMPs and the water quality improvements highlights the complexity of the relationship between conservation practices and water quality. Government-funded BMPs were apparently only directly responsible for a small part of the water quality improvements occurring in these watersheds. At least two confounding factors may have masked the relationship: privately-funded BMPs and varying effectiveness of government-funded BMPs. Even though the majority of the tracked BMPs were conversions from rill to sprinkler, the effectiveness of rill-to-sprinkler conversions in reducing turbid runoff varies substantially. For example, converting from rill irrigation to a solid-set sprinkler system on five percent slopes in a vineyard would reduce turbid runoff far more than a solid-set system on a flat, healthy pasture. However, given the spatial diversity of crops among the sub-basins, widespread but untracked privately-funded BMPs were likely the more significant factor. Privately funded BMPs implemented during these years included: more careful irrigation water management; installing sprinkler systems, drips systems and sedimentation basins with solely private funds; and use of polyacrylamide (PAM), a flocculant commonly used to reduce the turbidity of on-farm runoff. Unfortunately, privately-funded BMPs could not be quantified.

In addition to BMP implementation, factors not addressed in this report that could have affected the water quality include: (1) changing proportions of crop types within the six years evaluated; (2) on-farm water delivery rates; (3) piping irrigation return drains; and (4) decreased transport efficiencies in portions of drains with substantial aquatic plant and algal growth.

Conclusions

Water quality within Sulphur and Granger watersheds improved significantly during the 1997 to 2002 irrigation seasons. Concentrations, loads, and yields of suspended sediment, nutrients, and bacteria declined from year to year throughout the watersheds. Improved on-farm conservation practices offer the best explanation for observed declines in suspended sediment, turbidity, phosphorus, organic nitrogen+ammonia, and fecal coliform concentrations, loads, and yields.

In these irrigation return drains, suspended sediment concentrations strongly correlated with turbidity and total phosphorus concentrations but did not correlate with total Kjeldahl nitrogen or fecal coliform concentrations. Discharge rates did not correlate with concentrations of these constituents but weakly, inversely correlated with nitrate concentrations in Sulphur Creek Wasteway.

Unlike the other constituents, nitrate is transported primarily through shallow groundwater into the drains – not from surface water runoff.

Differences in water quality between the watersheds included generally higher turbidities and concentrations of suspended sediment, total phosphorus and fecal coliform in Granger sub-basins than in Sulphur sub-basins. Differences in crop type, density of dairies, soil types, and slopes may explain some of the differences in water quality.

Differences in government-funded BMP implementation rates did not directly correspond to water quality improvement rates. The relationship was likely masked by other variables that could not be quantified, such as privately-funded BMP implementation.

In 1997, concentrations of suspended sediment, phosphorus, and fecal coliform during the irrigation season generally were much higher than the non-irrigation season. The significant declines during subsequent years in irrigation season concentrations resulted in a narrowing gap. By 2002, irrigation season concentrations approached or, in some cases, were less than non-irrigation season concentrations (except for fecal coliform concentrations in Granger Drain), raising concerns about future effectiveness of current BMPs, which are largely directed towards irrigation practices.

The level of effort undertaken in the lower Yakima Valley to improve water quality was considerable, including over $26 million spent to implement BMPs, widespread efforts by diverse public agencies to support the conservation efforts of the landowners, and a locally-led enforcement program. Of the known acres improved throughout South Yakima Conservation District during the six years evaluated, 58% of the government-funded BMPs were implemented in the Sulphur and Granger watersheds, even though they account for only 23% of the irrigated acres within the district, reflecting the intensity of effort focused on these watersheds.

The water quality data reflect major improvements in soil and water conservation practices. After decades of effort, irrigation-induced erosion is no longer the dominant resource concern in the lower Yakima Valley.

References

[1] Surface-Water-Quality Assessment of the Yakima River Basin, Washington: Overview of Major Findings, 1987-91, Jennifer L. Morace *et al*, Water-Resources Investigations Report 98-4113, U.S. Department of the Interior, U.S. Geological Survey, p. 13.

[2] A Suspended Sediment and DDT Total Maximum Daily Load Evaluation Report for the Yakima River, Washington State Department of Ecology, July 1997, Publication No. 97-321.

[3] U.S. Census Bureau, based on 2000 census, from their webpage at: http://factfinder.census.gov/ home/. Web page accessed in February 2003.

[4] Natural Resources Conservation Service, from their webpage at http://efotg.nrcs.usda.gov/treemenuFS.aspx?Fips=53077& MenuName=menuWA.zip. Web page accessed in February 2003.

[5] Soil Survey of Yakima County Area Washington, U.S. Department of Agriculture, Soil Conservation Service, 1979 (p.6).

[6] Granger Drain Fecal Coliform Bacteria Total Maximum Daily Load Assessment and Evaluation: Final, Washington State Department of Ecology, October 2001, Publication No. 01-10-012.

[7] South Yakima Model Implementation Project, MIP Final Report, October 1982, South Yakima Conservation District.

[8] Personal communication, Dave Myra, Resource Conservation Development Council Coordinator, Natural Resources Conservation Service, December 14, 2004.

[9] Agricultural Return Flow Management in the State of Washington, prepared for the State of Washington Department of Ecology, by CH2M Hill, 1975.

[10] Watershed Management Plan Yakima River, Yakima River Basin Watershed Planning Unit and Tri-County Water Resources Agency, January 2003.

[11] South Yakima Conservation District Renewable Natural Resource Program, March 1977, USDA Soil Conservation Service.

[12] Water Quality in the Yakima River Basin, Washington, 1999-2000, Gregory J. Fuhrer *et al*, Circular 1237, U.S. Department of the Interior, U.S. Geological Survey.

[13] Concentrations and Loads of Suspended Sediment and Nutrients in Surface Water of the Yakima River Basin, Washington, 1999-2000 – with an Analysis of Trends in Concentrations, James C. Ebbert *et al*, Water-Resources Investigations Report 03-4026, U.S. Department of the Interior, U.S. Geological Survey.

[14] Granger Drain DNA Fecal Analysis Project, South Yakima Conservation District, May 2002.

[15] Fecal-Indicator Bacteria in the Yakima River Basin, Washington – An Examination of 1999 and 2000 Synoptic-Sampling Data and their Relation to Historical Data, Jennifer L. Morace and Stuart McKenzie, Water-Resources Investigations Report 02-4054, U.S. Department of the Interior, U.S. Geological Survey.

[16] Personal communication, Stuart McKenzie, McKenzie Consulting, December 11, 2003.

[17] Provisional data, personal communication, Hank Johnson, hydrologist, USGS, December 24, 2003.

[18] Furrow Erosion Nomograph, State of Washington, April 1983, Soil Conservation Service, W.Weller *et al.*